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Challenges in respect to supply of IMO 2020 0.5% sulphur regulation compliant bunker fuel at the Port of Colombo : lessons learnt and the way forward

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CHALLENGES IN RESPECT TO SUPPLY OF IMO 2020 0.5% SULPHUR REGULATION COMPLIANT BUNKER FUEL AT THE PORT OF COLOMBO

Lessons learnt and the way forward

By

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Sri Lanka

A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the reward of the degree of

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Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature):

(Date): 31 October 2020

Supervised by: Dr. Alessandro Schönborn 31 October 2020

Supervisor's affiliation: World Maritime University

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Ranaweera Mudiyanselage Ariyamanjula

Abstract

Title of Dissertation: **Challenges in respect to supply of IMO 2020 0.5% Sulphur regulation compliant bunker fuel at the Port of Colombo, Lessons learnt and the way forward**

Degree: **Master of Science**

This dissertation is a study on the challenges encountered in respect of complying with the new IMO 2020 0.5% Sulphur regulation at the Colombo port and an attempt to devise proposals to overcome the challenges and to develop the bunkering business giving due considerations to the lessons learnt, future regulations and trends in maritime sector.

Industry experts predicted many technical challenges with respect to the new 0.5% Sulphur VLSFO introduced to use in place of conventional 3.5% Sulphur HSFO due to its unfamiliar composition and properties. According to the feedback received for the *Questionnaire Survey*, despite of few minor issues reported in Colombo and inability to produce VLSFO at the local refinery, introduction of VLSFO for bunkering had been smooth with imported stocks. However, HSFO bunkering has been avoided due to the difficulties associated with comingling of both types of fuel oil, resulting in loss of business opportunity to supply HSFO to ships fitted with SOx scrubbers.

SWOT analysis conducted on the bunkering business in Colombo indicates high bunker prices and lack of infrastructure facilities as main barriers to develop bunkering business. Development of the local refinery was identified as the most suitable option to provide bunker fuel at a competitive price. However, it was also noted that implementation of this project has been held up for more than a decade due to unavailability of finance.

Eight development scenarios for bunkering were developed to evaluate with respect to the compliance with the future fuel mix, infrastructure development cost, increase in operational complexity, contribution to GHG emission, technical knowhow, fuel availability and throughput capacity using the TOPSIS technique. Results of the TOPSIS analysis favors the scenarios focused on development of infrastructure to re-introduce HSFO while discouraging investment on LNG for 2030. However, forecast of future fuel mix for 2050 indicates requirements of preparing for LNG and Ammonia as ship bunker fuels.

KEYWORDS: IMO 2020, Bunkering, Colombo, Sulphur, Regulation, VLSFO, HSFO, future fuel mix, TOPSIS

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List of Abbreviations

ABS	American Bureau of Shipping
API	American Petroleum Institute
ECA	Emission Control Area
CIMAC	International Council on Combustion Engines
CAPEX	Capital Expenditure
CPC	Ceylon Petroleum Corporation
EEDI	Energy Efficiency Design Index
EMSA	European Maritime Safety Agency
EPA	Environmental Protection Agency
GOSL	Government of Sri Lanka
GWP	Global Warming Potential
HSFO	High Sulphur Fuel Oil
ICS	International Chamber of Shipping
IFO	Intermediate Fuel Oil
IMO	International Maritime Organisation
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
JCT	Jaya Container Terminal
JIG	Joint Industry Guidance
LNG	Liquefied Natural Gas
m/m	Mass by mass
MARPOL	International Convention for the Prevention of Pollution from Ships
MCDA	Multi Criteria Decision Analysis

MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
NOx	Nitrogen Oxides
PAS	Publicly Available Specification
PM	Particulate Matter
QRA	Quantitative Risk Assessment
QualRA	Qualitative Risk Assessment
SIN	Shipping Intelligence Network
SLPA	Sri Lanka Ports Authority
SOLAS	International Convention on Safety of Life at Sea
SOx	Sulphur Oxides
SWOT	Strength, Weaknesses, Opportunities & Threats
TEU	Twenty-foot Equivalent Unit
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
ULSFO	Ultra Low Sulphur Fuel Oil
UNCTAD	United Nations Conference on Trade and Development
USD	United States Dollar
VLSFO	Very Low Sulphur Fuel Oil

1. CHAPTER 1 - Introduction

1.1 Background

1.1.1 Port of Colombo

The port of Colombo ranks 24th in the Lloyd's List of One Hundred Ports (2019) with a record-breaking handling of 7.6 million TEUs in 2019. Its strategic geographical location has enabled Colombo port to serve as a very successful container transshipment hub in the region.

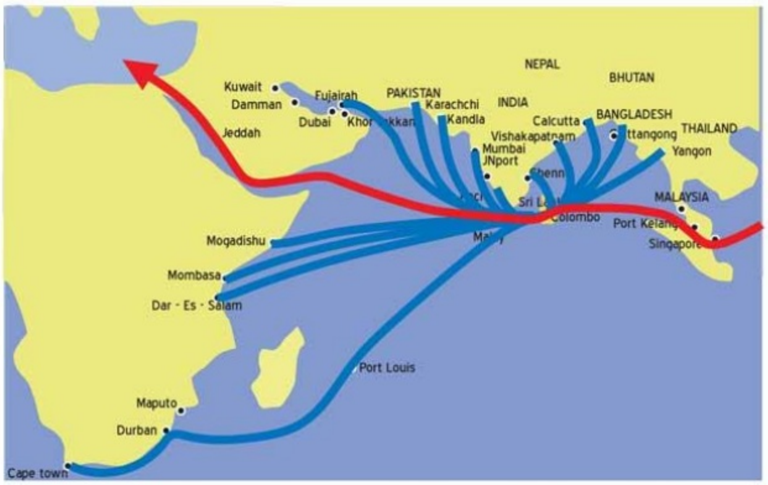

Figure 1. International maritime routes connecting Port of Colombo. From "Colombo Port– Location", SLPA, 2020. (https://www.slpa.lk/port-colombo/location)

According to SLPA (2020a), "Cargo originating from and destined to Europe, East and South Asia, the Persian Gulf, and East Africa is conveniently and efficiently connected through the Colombo Port". Alphaliner has ranked Colombo port as the world's fastest growing port in year 2018 (SLPA, 2018).

It is extremely important to supply the bunker fuel required for the ships that call into Colombo port at the right quality, quantity and price in order to make the Colombo port more attractive to shipping lines. However, with the implementation of IMO 2020 Sulphur regulation new challenges to the bunkering activities have emerged.

1.1.2 IMO 2020 0.5% Sulphur regulation

From 1 January 2020, as stipulated under MARPOL Annex VI regulation 14, the allowable Sulphur content of fuel used on board ships operating outside designated emission control areas (ECA) was reduced from 3.5% m/m to 0.5 % m/m unless there is an approved alternative mean such as exhaust gas scrubber installed onboard to reduce emission of Sulphur oxides (SOx). This new regulation is expected to significantly reduce the amount of SOx originating from maritime vessels and is anticipated to derive significant health and environmental benefits for the world, particularly for coastal population and the environment.

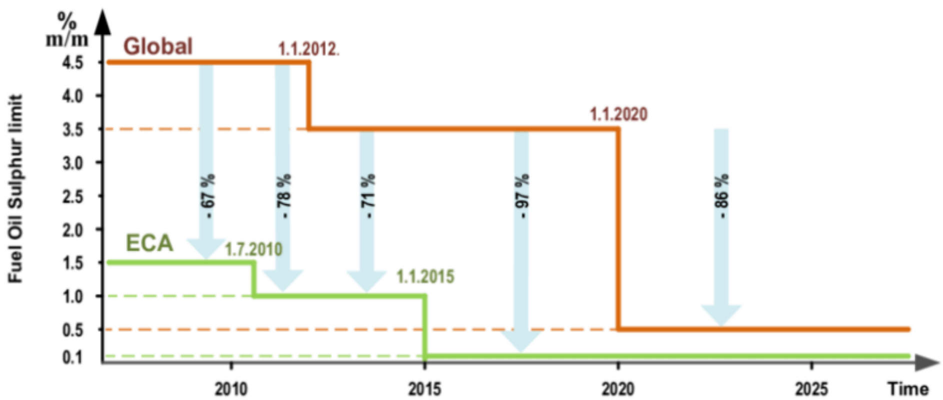

Figure 2. MARPOL Annex VI regulation 14-sulphur limits for marine fuel. From "Overview of MARPOL ANNEX VI regulations for prevention of air pollution from marine diesel engines" by L. Campara, N. Hasanspahić & S. Vujicic, 2018, p.6.

As indicated in the Figure 1 above the reduction in the allowable limit of Sulphur in fuel oil in 2020 was 86%. According to a study on the human health impacts of SOx emissions from ships, submitted to IMO's Marine Environment Protection Committee (MEPC) in 2016 by Finland, the air pollution from ships would contribute to more than 570,000 additional premature deaths worldwide between 2020-2025, unless the implementation of global SOx limit reduction of 0.5% is done by 2020 (IMO, 2016 a). Apart from the adverse health impacts, SOx emissions also contributes to acid rains that can harm the sensitive ecosystems (EPA, 2019). As such, it is extremely important for the shipping industry to comply with this regulation.

However prior to implementation of the new regulation, it was noted that many challenges were present with respect to supplying fuel that complies with the new regulation by 1 January 2020, especially for developing countries that lacks the technical and financial capacity to cope up with such a drastic change. It was also observed that, many countries and shipping lines did not expect this regulation to take effect so soon despite the fact that during the year 2016 IMO had confirmed the implementation date as 1 January 2020. Further, even though Ultra Low Sulphur Fuel Oil (ULSFO) with 0.1% m/m Sulphur has been in use in the ECAs, a globally accepted fuel standard that specifies 0.5% m/m Sulphur in the category of Very Low Sulphur Fuel Oil (VLSFO) was not available until the end of third quarter of 2019.

1.1.3 Applicable Standard for Bunker Fuel Oil

ISO 8217 standard specifies the requirements of fuels for use in marine engines and boilers prior to conventional on-board treatment. The latest edition of ISO 8217 was published in March 2017. Since a revision of ISO 8217:2017 was not possible within the available period to facilitate the IMO 0.5 % Sulphur regulation by 1 January 2020, ISO developed a Publicly Available Specification (PAS) i.e. "ISO/PAS 23263:2019 Petroleum products - Fuels (class F) - Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0.50 % sulphur in 2020" (ISO, 2019).

The PAS, which was published on 18 September 2019, is expected to address the anticipated fuel characteristics and properties of the marine fuels that will be introduced to the market to meet the new IMO 2020 regulation and will be used in combination with ISO 8217:2017. It gives technical considerations that will apply to particular fuels including the compatibility between fuels, stability, viscosity and additional information on ISO 8217:2017, Annex B (ISO, 2019).

1.2 Research Problem

There are considerable challenges for the bunkering industry at the Colombo port with respect to complying with the new IMO Sulphur regulation. This research intends to examine the most immediate and future challenges and lessons learnt with respect to the implementation of IMO 2020 Sulphur regulation at the Colombo port. Further, it is intended to identify future proof options to develop bunkering industry at the Colombo port giving due attention to the upcoming regulations intended to reduce GHG emissions in maritime transportation.

1.3 Motivation

Sri Lankan government has made a policy decision to become the premier maritime and economic hub in the Indian Ocean. Ship bunkering is a key service that a maritime hub must possess to attract ships. A port with attractive bunkering facilities at a strategic location such as Colombo will enable ships to carry more cargo by reducing bunker volumes onboard due to having a refueling option in the middle of east-west shipping route. According to Fernando (2017), more than 60,000 ships ply the east-west maritime route annually, passing Sri Lanka, carrying two-thirds of the world's oil and half of all container shipments. However, Sri Lanka has not been able to make full use of this opportunity and there is still great potential to earn a huge amount of foreign exchange by providing services to these ships including bunker.

1.4 Aims and objectives

1.4.1 The **aim** of this research project is to provide recommendations to overcome the barriers to comply with the new IMO Sulphur regulation during the next ten years and to provide long-term recommendations to grow the bunkering business at Colombo port in environmentally sustainable manner giving due considerations to future regulations.

1.4.2 **The objectives** of this research project are as follows:

i. To examine the status of bunkering activities and the actions taken to meet the new regulations and lessons learnt after implementation of new IMO 2020 0.5 % Sulphur regulation.
ii. Conduct SWOT analysis in relation to bunker business at Colombo port.
iii. To identify viable options for bunker fuel for the 2020-2030 and 2030-2050 periods.
iv. To conduct Multiple Criteria Decisions Analysis to identify the most suitable bunker fuel mix and infrastructure development requirement for the 2020-2030 period and 2030-2050 period at the Colombo port.

1.5 Research questions

1. What are the requirements and available options in complying with IMO 2020 Sulphur regulation with respect to bunker supply at Colombo port?
2. What lessons have been learnt after the implementation of new IMO Sulphur regulation?
3. What future changes are expected in maritime regulations related to bunker fuel?
4. What is the fuel mix of the current shipping fleet and how will it change in future?
5. What are the merits and demerits of available options for bunkering in future?
6. What fuel types and demand quantities should be considered for future developments?

1.6 Research Methodology

A *literature review* on the background of the IMO 2020 0.5 % Sulphur regulation, preparedness, common issues and management strategies will be conducted. The existing infrastructure facilities, bunkering operations at the Colombo port will be reviewed to identify the challenges to comply with the new regulations.

Questionnaire survey will be conducted in order to evaluate the status of the preparedness for the implementation and lessons learnt after implementation of the regulation and also to fill the data gaps. A *SWOT analysis* will be conducted in relation to bunkering business at Colombo port to assess the strengths, weaknesses, opportunities, and threats in the view of developing the most suitable bunkering options. Quantitative analysis will be done to identify the most recent fuel mix of the shipping fleet and future trends.

Based on the lessons learnt and the knowledge gained through the *literature review*, *questionnaire survey*, and the outcome of *SWOT analysis*, I will devise immediate solutions to comply with the new regulation and propose further development options for future.

Scenario analysis using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) will be conducted to select the most appropriate bunker fuel options and related developments for 2020-2030 and 2030-2050.

1.7 Expected Results

It is expected that the findings of this research project will be used to develop bunkering industry in Colombo port by overcoming the challenges set forth by new industry requirements and regulations. Accordingly, the findings will assist the Sri Lankan policy makers to address practical issues in the course of developing strategies to become a maritime and economic hub in the Indian Ocean.

1.8 Potential Limitations

The main limitation for this research is the limited time since the implementation of the IMO 2020 regulation. However, it is possible to make use of the lessons learnt after the implementation of the regulation and to focus on long term recommendations to develop bunkering industry under this research proposal. Further, obtaining information on issues on bunker fuel and operations from the bunker suppliers could be difficult due to the fear of effect to their business activities.

2. CHAPTER 2 – Bunkering at Colombo Port

2.1 Infrastructure facilities for Bunkering

Bunkering activities at the Colombo port are currently being performed by several private sector operators. These operators share a common user facility at Colombo called “JCT oil bank” for storage and transfer of bunker fuel. The JCT oil bank is managed by the Jaya Container Terminal (JCT) Limited, which is a fully owned subsidiary company of the Sri Lanka Ports Authority (SLPA). The primary business activity of the JCT Limited is storing of marine fuel on behalf of the bunker operators and supplying it when required to conduct the bunkering operations. This facility is located in a 9 acres land at the Bloemendhal area in Colombo 15 and at present, there are 13 fuel tanks having a total capacity of 35,000 MT to store marine fuel.

The following table shows the available tanks and their capacities at the JCT oil bank as at the year 2019;

Table 1. Fuel Storage Tank Capacities at the JCT Oil Bank

	Tank No.	Product	Volume (m^3)	Total Volume (m^3)
1	101	HSFO 380	4,892	21,011
2	102	HSFO 380	1,070	
3	103	HSFO 380	1,225	
4	104	HSFO 380	7,834	
5	117	HSFO 380	5,990	
6	107	IFO 180	5,760	5,760
7	105	MGO	1,196	12,656
8	106	MGO	4,363	
9	108	MGO	1,129	
10	109	MGO	1,318	
11	110	MGO	1,318	
12	111	MGO	2,014	
13	112	MGO	1,318	

Figure 3. Tank farm layout at the JCT oil bank. From Google map. 2020.

Receiving and discharging the oil from the facility to sea going vessels and bunker barges are primarily performed using the pipelines connecting the JCT oil bank with the South jetty and the New North pier of Colombo port. There are more pipeline connections to the Dolphin Tanker Berth (DTB) and also to Kollonnawa oil storage terminal that is linked to the Sapugaskanda oil refinery to receive oil.

2.2 Bunkering operations

Seven bunker licence holders have entered into agreement with the JCT Limited for the utilization of the Oil bank. These bunker operators primarily depend on the oil imports conducted by themselves as well as supplies from the Ceylon Petroleum Corporation (CPC), which is the National oil company in Sri Lanka. Before all these companies entered the ship bunkering business, Ceylon Petroleum Corporation conducted bunkering through its fully owned subsidiary company and it had a monopoly over the bunkering business in Sri Lanka; its bunkering business was privatized in 2002. All the aforementioned bunker operators supplied High Sulphur Fuel Oil (HSFO) grades of 180cSt, 380cSt and Marine Gas Oil (MGO) complying with ISO 8217 standard prior to introduction of Very Low Sulphur Fuel Oil (VLSFO) at the end of year 2019 in line with the implementation of new Sulphur regulation in 1 January 2020.

Total bunker fuel deliveries as recorded by the JCT oil bank are given below for the period of 2009 to 2018.

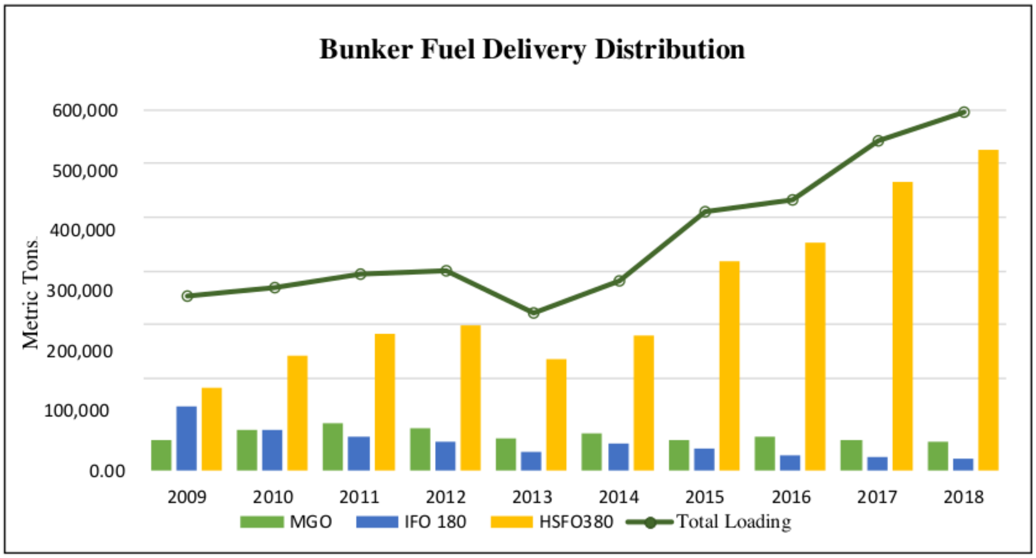

Figure 4. Bunker Fuel delivery at the JCT oil bank 2009-2018. [Data Source: JCT Ltd.]

There had been a steady growth in bunkering business in Colombo during the past up to the year 2018 as indicated in the Figure 4 above. The main revenue-generating product had been HSFO 380. However, according to the feedback received for the questionnaire given to the bunker operators, bunkering at Colombo port is not an attractive bunkering option for the ships due to the high price of bunker fuel at Colombo. Hence, normally ships tends to buy the minimum quantities required at Colombo.

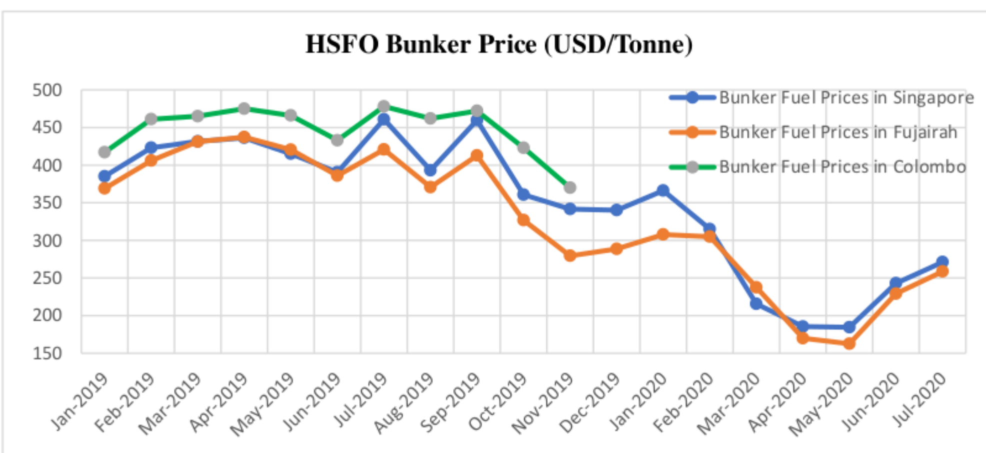

Figure 5. HSFO Bunker Prices Comparison for Colombo, Singapore & Fujairah. [Data source: Lanka Marine Services (Pvt) Ltd., Clarkson Research]

Sale of HSFO had been discontinued since December 2019 after introduction of VLSFO. Given below is a comparison of bunker fuel prices in Colombo (as provided by Lanka Marine Services (Pvt) Ltd) with bunker fuel prices in Fujairah and Singapore obtained from Clarksons Research shipping intelligence network (SIN).

Table 2. Bunker fuel prices comparison for Colombo, Singapore & Fujairah. [Data source: Lanka Marine Services (Pvt) Ltd., Clarksons Research SIN]

	Bunker Fuel Prices in Singapore ($/Tonne)			Bunker Fuel Prices in Fujairah ($/Tonne)			Bunker Fuel Prices in Colombo ($/Tonne)		
Month	**VLSFO (0.5% Sulphur)**	**MGO**	**HSFO 380cst (3.5% Sulphur)**	**VLSFO (0.5% Sulphur)**	**MGO**	**HSFO 380cst (3.5% Sulphur)**	**VLSFO (0.5% Sulphur)**	**MGO**	**HSFO 380cst (3.5% Sulphur)**
Jan-2019	-	549	385	-	725	369	-	720	417
Feb-2019	-	596	423	-	734	406	-	739	461
Mar-2019	-	617	432	-	732	431	-	759	465
Apr-2019	-	626	436	-	741	437	-	765	475
May-2019	-	621	415	-	719	421	-	738	466
Jun-2019	-	580	391	-	689	386	-	707	433
Jul-2019	-	606	461	-	694	421	-	706	478
Aug-2019	-	586	393	-	677	371	-	675	462
Sep-2019	554	594	460	598	693	413	-	691	472
Oct-2019	540	580	361	567	679	327	-	673	423
Nov-2019	549	582	342	574	684	279	-	668	370
Dec-2019	626	626	340	632	714	289	705	750	-
Jan-2020	663	664	366	687	743	308	809	808	-
Feb-2020	503	513	315	508	636	305	612	640	-
Mar-2020	327	344	216	341	510	238	433	522	-
Apr-2020	250	262	185	250	410	170	313	436	-
May-2020	257	270	185	255	352	163	323	452	-
Jun-2020	316	351	243	317	407	229	364	440	-
Jul-2020	340	388	271	336	443	259	370	436	-

It can be observed that at the beginning of year 2019, when the market was stable, the HSFO price in Colombo has been higher than Singapore and Fujairah price by around 35-50 USD/T. Price difference for MGO has been very high between Colombo and Singapore in the range of 140-170 USD/T at the beginning of 2019 and the price difference with Fujairah has not been significant.

2.3 Ships calling at Colombo port

Given below are the statistics about ships that have called into the Colombo port during 2016-2018.

Table 3.Total number of ship calls to Colombo port. [Data From: SLPA Annual report 2016, 2017 & 2018.]

Type of ship/ purpose of call	No of Ships 2016	No of Ships 2017	No of Ships 2018
Container	3804	3683	3739
Conventional	40	56	51
Dry Bulk	194	157	153
Liquid Bulk	191	210	210
Roll on Roll off	51	67	31
Other Cargo	0	02	01
Passenger	43	44	55
Bunkering	29	44	33
Repairs	46	58	50
Other services	7	8	8
Total No of Ships	4405	4329	4331

It can be observed that very few number of ships have arrived at the Colombo port for the purpose of bunkering i.e. 29 ships in year 2016, 44 ships in year 2017 and 33 ships in year 2018. Being located very close to the main east- west shipping route that is used by more than 60,000 ships annually, the number of vessels comes to Colombo port for the purpose of bunkering is very small.

It can be further observed that, Colombo port being the premier container transshipment hub in the region, the main category of ship that calls into Colombo port is container ships. Container ships account for nearly 90% of the cargo ships arriving to Colombo port.

2.4 Challenges to make compliant fuel available at the Colombo Port

Challenges to make compliant fuel available at the Colombo port are discussed below with respect to the available straightforward options i.e. importation of compliant fuel and local production to fulfill the immediate requirement.

2.4.1 Importation of Compliant VLSFO

Bunker fuel is mainly imported to Colombo from Singapore and Fujairah which are also known to be Bunker oil hubs. Even though it is possible to import and supply compliant fuel, prior to the implementation of the new regulation, industry experts pointed out many challenges with respect to handling of fuel due to the expected composition of this new fuel grade. Main concerns raised were the compatibility and stability of VLSFO as this new fuel is expected to be a blended product with ratios that are not familiar to the industry. It was anticipated that as the demand for 2020 compliant low sulphur fuels increases, new grades of fuels will enter the market in the form of distillates, blends and other streams such as vacuum gas oil (ICS, 2019).

CIMAC (2019) reported that, "The increasing restrictions on marine fuel sulphur content, defined by MARPOL Annex VI Regulation 14.1.3, have changed the primary blend target from viscosity and density to sulphur. Whereas viscosity and/or density are at a relatively consistent level within the same fuel grades in the pre-2020 fuels, the implications of this means that marine fuels post 2020 are expected to result in a wide variability of fuel formulations and characteristics alike".

According to Barsamian (2019), an enormous increase in the number of blends purportedly meeting new specifications will be seen in 2020 due to desperation to achieve the cheapest possible blends by the manufacturers and a terrible price will have to be paid unless careful attention is given with respect to storing and handling throughout the supply chain.

In order to fulfill the bunker requirement at Colombo port, it is required to maintain stocks of 0.5% VLSFO for ships without scrubbers and stocks of 3.5% HSFO for ships with scrubbers installed. There are limited number of tanks available at the common user facility at Colombo and because of that comingling of different batches of fuel oil (even for the same Sulphur %) is a challenge if those batches are not compatible. According to JCT Ltd., the tank farm reached its maximum capacity in 2018 with a total handling of around 600,000 MT for the year and it was a great challenge to manage the receiving and dispatching operations, which had to be synchronized with ship schedules. Since, there is no availability of excess storage capacity at the oil bank, a slight change in receiving or dispatch schedule can cause delaying of both way operations resulting in delays to ships.

Further, the oil bank has only 02 fuel transfer pipelines for fuel oil grades where one line is dedicated for receiving oil and other line for dispatching oil to bunker barges and ships. As such, the operation of HSFO 380 with Sulphur content 3.5% and VLSFO with Sulphur content 0.5% can not be handled simultaneously. Hence, for the simultaneous operation of VLSFO and HSFO, additional pipelines and storage capacities are required to avoid delays and achieve operational flexibility.

Mixing of incompatible fuel oil will lead to stability issues causing formation of sludge. Such fuel is not suitable for use in ship fuel systems and engines as it can clog filters, block fuel lines & fuel treatment units, and result in sludge/deposit formation inside engines. This is a very serious concern for 0.5% m/m VLSFO as it can involve blending of middle distillates from various sources in higher blending ratios (containing various compositions of aromatic, paraffinic or naphthenic hydrocarbons) in comparison to the 3.5% Sulphur HSFO which usually comes as a straight run product from refineries or with limited amount of blending.

According to ISO/PAS 23263:2019, "Historically, fuels within the same grade were very similar in kinematic viscosity and typically close to the maximum limit of the ordered grade. The kinematic viscosity is expected to vary widely for 0,50 mass % S fuels, even within the same grade and is no longer the controlling characteristic that it once was. For example, some lower viscosity fuels may have other characteristics such as density, carbon residue and catalyst fines typical of higher viscosity grades" (ISO, 2019).

Risk of increase in "Cat fines' is another challenge that is predicted for VLSFO as a result of additional catalytic cracking in refineries to obtain low Sulphur stocks to produce VLSFO by blending. "Cat fines are created as a result of catalytic cracking in the crude oil refining process, during which tiny fragments of the catalyst material become entrained in the refined products and residues. These cat fines are typically a combination of aluminum and silicon and are very hard, abrasive particles. In limited quantities they can cause gradual engine wear. If present in larger amounts, they can cause significant damage to engine components such as fuel pumps, fuel injection valves, cylinder liners and piston rings. In extreme cases, they can result in the total failure of the engine" (ABS, 2019). "Cat Fines in the fuel can be harmful to the Boiler System in terms of causing damage and wear to pumps, filters, the burner and boiler pressure part itself. Existence of cat fines can also impact combustion optimization" (Alfa Laval, 2019).

Apart from the above discussed technical challenges, there are financial challenges due to the cost involved with the importation of fuel. All the extra precautions that are to be taken during importation and handling will increase the cost making it extremely difficult to compete with other ports in the region due to high bunker oil prices.

2.4.2 Local production of Compliant VLSFO

The next immediate option is to produce the compliant VLSFO at the local oil refinery situated in Sapugaskanda. This should also be a cheaper solution compared to importation of fuel from Singapore or Middle East as the cost of importation can be eliminated. Further, it will reduce the issues of compatibility and stability associated with different batches. There are pipeline connections from Sapugaskanda refinery to Colombo port and JCT oil bank via the Kollonnawa oil storage terminal.

Figure 6. Infrastructure facilities related to Petroleum oil in Colombo

The Sapugaskanda refinery, which is the only oil refinery in Sri Lanka was commissioned in year 1969. It initially had the capacity to process 38,000 barrels per day using Iranian light crude oil and its current capacity is 50,000 barrels per day. Crude oils similar to Iranian light such as Upper Zakum, Arabian light were also able to process in the plant meeting required specifications (CPC, 2020). After imposing trade sanctions on Iran, it was not possible to import Iranian light crude oil and hence Murban sweet crude oil is currently used for the plant.

This refinery does not possess modern processing units or a Sulphur Recovery unit (SRU). Because of this, the Sulphur level of produced diesel is around 0.25 % m/m which is quite high compared to diesel produced in modern refineries. At the current configuration, using Murban sweet cude oil as the input, the minimum Sulphur level of HSFO produced at the local refinery is 2.0% m/m and it is not currently capable of producing 0.5% m/m VLSFO as a straight run product.

The process units of the Sapugaskanda refinery are indicated in the Figure below.

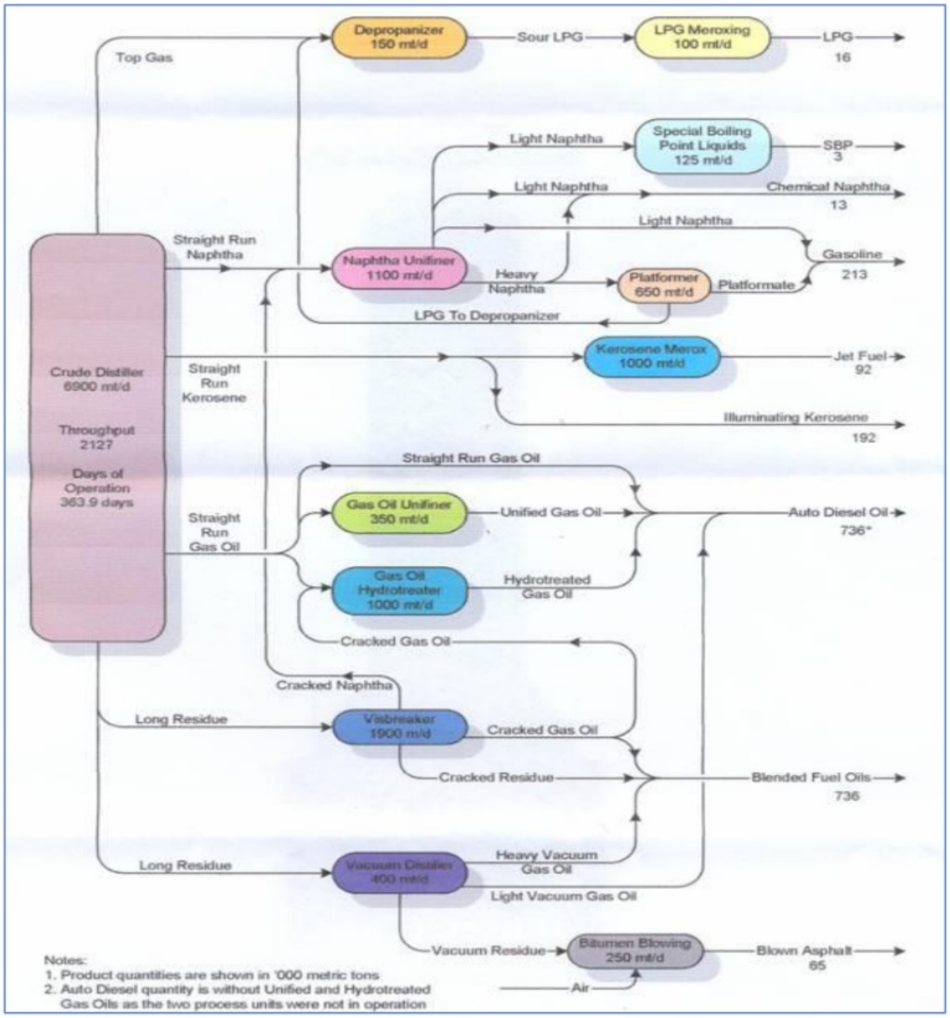

Figure 7. Process configuration of the Sapugaskanda oil Refinery. From "Refinery", by CPC, 2020 (http://ceypetco.gov.lk/refinery/).

Due to the high percentage of Sulphur level in middle distillate products (in the range of Diesel & Kerosene), it is not economical to produce 0.5 % m/m VLSFO by blending residual fuel with the middle distillate products at the Sapugaskanda refinery as done in other modern refineries, where middle distillate products with sufficiently low level of Sulphur are available to achieve economical blending ratios.

Switching to very low Sulphur crude oil is another alternative, as it would enable production of very low Sulphur products. However, this also requires certain modifications to the refinery and it can be an expensive solution considering the price of very low Sulphur crude oil and the cost of modifications.

Viability of above options mainly depend on the price difference between 0.5% VLSFO, 3.5 % HSFO and MGO. Given below is a comparison of monthly bunker fuel prices at Singapore and Fujairah during the past year.

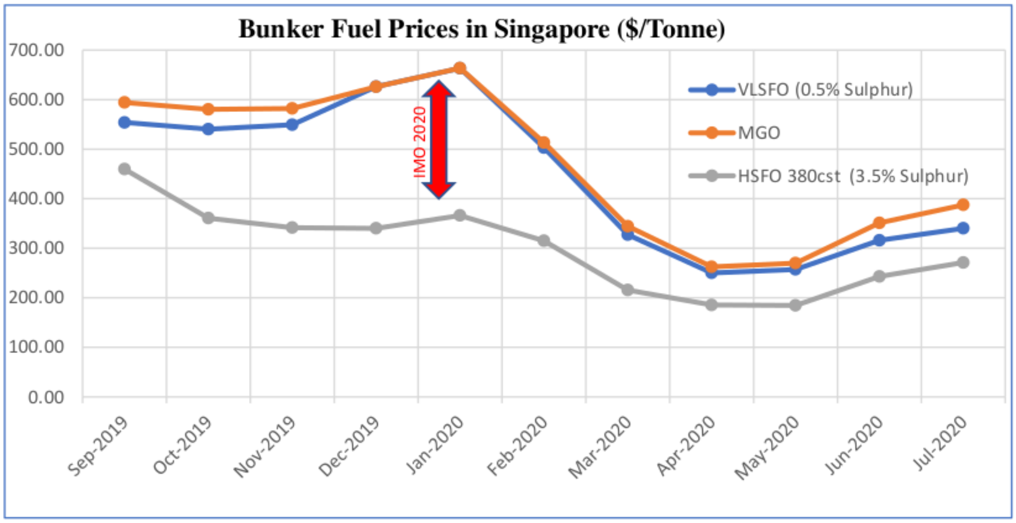

Figure 8. Monthly bunker fuel prices in Singapore [Data source: Clarkson Research SIN.]

Table 4. Monthly bunker fuel prices in Singapore [Data source: Clarkson Research SIN]

Bunker Fuel Prices in Singapore ($/Tonne)				
Month	**VLSFO (0.5% Sulphur)**	**MGO**	**HSFO 380cst (3.5% Sulphur)**	**Price Difference between VLSFO and HSFO**
Sep-2019	553.88	594.25	459.63	94.25
Oct-2019	540.38	580.38	360.75	179.63
Nov-2019	549.30	582.15	341.55	207.75
Dec-2019	626.25	626.00	340.13	286.13
Jan-2020	663.35	663.60	366.15	297.20
Feb-2020	503.00	513.25	315.00	188.00
Mar-2020	327.38	344.38	215.56	111.81
Apr-2020	250.19	262.44	185.44	64.75
May-2020	257.25	269.90	184.50	72.75
Jun-2020	316.00	351.19	243.00	73.00
Jul-2020	340.25	387.55	271.15	69.10

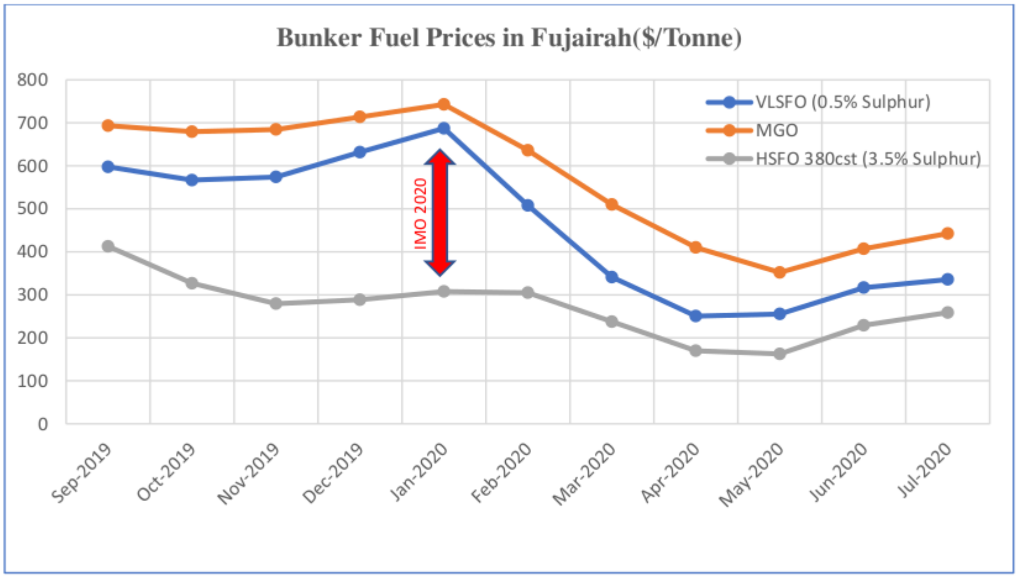

Figure 9. Monthly bunker fuel prices in Fujairah. [Data source: Clarkson Research.]

Table 5.Monthly bunker fuel prices in Fujairah. [Data source: JCT Ltd.]

Bunker Fuel Prices in Fujairah ($/Tonne)				
Month	**VLSFO (0.5% Sulphur)**	**MGO**	**HSFO 380cst (3.5% Sulphur)**	**Price Difference between VLSFO and HSFO**
Sep-2019	597.50	693.38	412.75	184.75
Oct-2019	566.69	679.38	326.81	239.88
Nov-2019	574.10	684.45	279.45	294.65
Dec-2019	631.69	713.75	288.63	343.06
Jan-2020	687.15	742.85	307.75	379.40
Feb-2020	507.75	635.94	304.94	202.81
Mar-2020	341.19	510.00	237.56	103.63
Apr-2020	250.44	410.06	169.94	80.50
May-2020	255.45	351.95	162.60	92.85
Jun-2020	316.69	407.13	229.19	87.50
Jul-2020	335.70	442.60	258.65	77.05

It can be observed that with the implementation IMO 2020 Sulphur regulation on 1 January 2020, which demanded to use fuel with Sulphur content 0.5% m/m or below unless exhaust gas scrubbers are fitted, the price of VLSFO and MGO have increased drastically and the gap between the low Sulphur fuel and high Sulphur fuel have increased. According to Clarksons Research (2020a), the number of ships fitted with scrubbers by the mid of January 2020 were 2353 which is about only 2.4 % of the total world fleet and equal to 12.6% of total gross tonnage of world fleet. Hence, the demand for HSFO had dropped while the demand for VLSFO has sharply increased. This has resulted in widening the price gap between low Sulphur fuel and HSFO by more than 300 USD per ton at the beginning of the year. However, drastic drop in oil prices at the end of the first quarter of the year owing to the crisis situation due to COVID-19 pandemic has resulted in narrowing the price difference between low Sulphur fuel to HSFO to around 70 USD per ton. As such, investments to produce VLSFO remains unattractive with too much uncertainty, which is very typical in oil market.

2.5 Impact on Bunkering Operations due to IMO 2020

Introduction of VLSFO at Colombo port was done at the end of year 2019. There have been several meetings with the JCT Ltd and bunker operators to prepare for this introduction. Initially it has been proposed to have a floating storage dedicated for VLSFO which is to be shared by all the operators and to import single parcel shared by all the operators. However, later on it had been agreed to use the existing facilities with tank cleaning and pipeline flushing to suit the new batches of fuel oil.

Table 6. Total Bunker Fuel Deliveries at JCT Oil Bank during 2015- 2020. [Data Source: JCT Ltd.]

	VLSFO		**IFO 180**		**HSFO 380**		**MGO**		**Total (MT)**
Year	**MT**	**%**	**MT**	**%**	**MT**	**%**	**MT**	**%**	
2015	-	0.0%	38,172	8.8%	347,143	79.6%	50,714	11.6%	436,030
2016	-	0.0%	26,610	5.8%	378,300	82.0%	56,522	12.2%	461,432
2017	-	0.0%	23,627	4.2%	481,239	86.4%	52,007	9.3%	556,873
2018	-	0.0%	19,821	3.3%	533,176	88.6%	48,593	8.1%	601,590
2019	6,188	1.3%	3,380	0.7%	433,071	88.1%	48,677	9.9%	491,315
2020 (up to July)	171,382	75.3%	-	0.0%	101	0.0%	56,162	24.7%	227,645

Based on the bunker fuel delivery data a sharp drop in total deliveries can be observed after year 2019 where delivery of HSFO has almost become zero during year 2020 (up to July). This is due to avoiding of HSFO intake after introduction of VLSFO at the end of year 2019 by the bunker operators due to the fear of issues with mixing of incompatible batches of VLSFO and HSFO. At the same time, it can be observed that the total fuel oil deliveries in 2020 are lower compared to previous years. This could be due to tendency of reducing bunkering in different locations by ships to avoid compatibility issues pertaining with VLSFO and non-availability of HSFO in Colombo for ships fitted with scrubbers. It is also noticeable that total sale of MGO up to mid of 2020 exceeds the total annual sale of MGO in previous years.

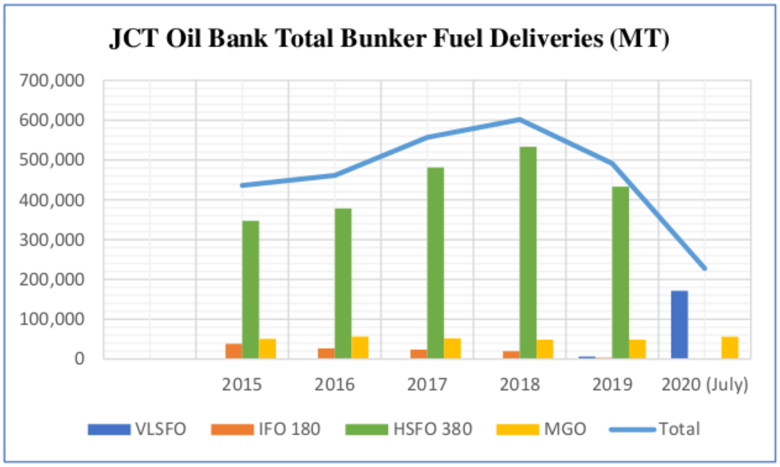

Figure 10. Total Bunker Fuel Deliveries at JCT Oil Bank (2015-2020). [Data source: JCT Ltd.]

After January 2020 fuel delivery composition at Colombo has been changed from 88% HSFO, 10% MGO, 2% IFO 180 to 75% VLSFO and 25% MGO.

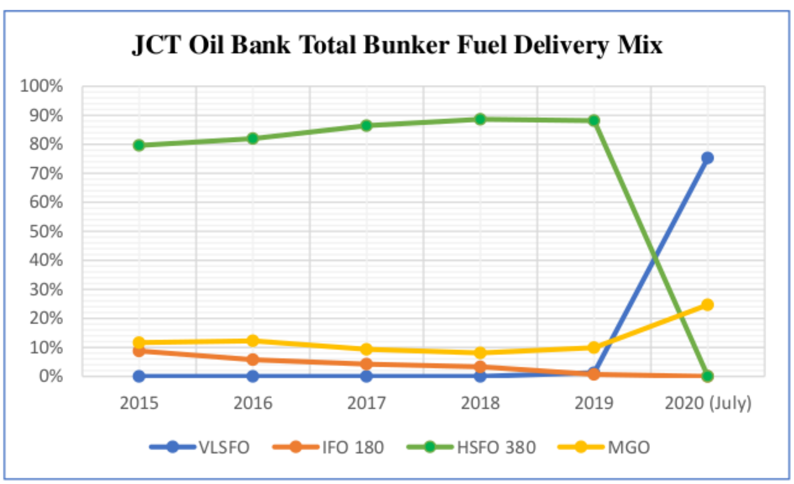

Figure 11. Bunker Fuel Delivery Mix of JCT Oil Bank (2015-2020). [Data source: JCT Ltd.]

2.5.1 Fuel quality related issues encountered after implementation of IMO 2020

Due to difficulty of handling both VLSFO and HSFO, bunker operators have avoided intake of HSFO to the JCT oil bank after December 2019 resulting in loss of business opportunity in HSFO. According to the feedback received for the questionnaire survey, there had been issues with tank cleaning to accommodate VLSFO at the initial period of introduction of VLSFO to the JCT oil bank. However, this issue had been resolved with the depletion of HSFO stocks and proper tank cleaning. Fuel delivery pipelines had been flushed with Low Sulphur MGO to clean out the residues.

With respect to the VLSFO deliveries, the main issue reported was the low viscosity of VLSFO and occasional too low flash point and variation in density. Out of the three responses received for the *questionnaire survey*, two bunker operators have had 10 complaints regarding the low viscosity and occasional low flash point during the first six months of 2020. Another bunker operator indicates variation in density as an issue encountered.

Regarding variations in viscosity of VLSFO, ISO/PAS 23263:2019 indicates the requirement of communicating the kinematic viscosity of the fuel prior to delivery. It also recommends the users to pay particular attention to the correct temperature and viscosity settings in the fuel system as different viscosity fuels should be adjusted to the correct temperature to comply with the machinery requirements (ISO, 2019).

According to Alfa Laval (2019), high viscosity variation from the different VLSFO is expected and "it is a requirement to always test the fuel viscosity and to manually input the new heating set point and alarm/trip set point (high and low) in the control system in respect with the viscosity-temperature chart".

Flash point is a very important parameter of fuel with respect to the risk of fire/ explosion. Flash point of VLSFO is set at 60 °C minimum in ISO 8217 standard in accordance with the relevant requirements under the International Convention for Safety of Life at Sea (SOLAS). However, according to ABS(2019), even if the fuels bunkered complying with specifications can develop flammable vapors due to fuel heating in ship tanks. Hence, ABS (2019) recommends following provisions for ships to deal with fuel with potential low flash point:

- "Ability to bypass heater or heat tracing".
- "Automatic shutdown of heating upon detection of high temperature limit (typically 10°C below flashpoint)".
- "Automatic shutdown of heating if the heating element is not submerged."

- “Identify additional hazardous areas due to the use of the fuel with potential low flash point.”
- “Avoid uncertified electrical equipment in the vicinity of fuel tank vent outlet”

ABS (2019), indicates that even though the density of VLSFO complies with ISO 8217 specifications, it may differ from 3.5 % HSFO due to different production processes and it could affect the operation of purifiers on board ships and the reading of tank gauging system, leading to the potential malfunction of these components unless settings of the relevant equipment are adjusted to match with the density of VLSFO.

Despite the issues discussed above, fuel delivery operations have been generally smooth since tank cleaning at the JCT oil bank to accommodate VLSFO. However, with respect to the total sale of fuel oil there is a decline, which could also be due to the non-availability of HFSO and less shipping activities due to the COVID-19 global pandemic.

3. CHAPTER 3 – Development Options for Bunkering Operations at Colombo

3.1 SWOT Analysis

SWOT Analysis considering the strengths, weaknesses, opportunities and threats on the bunkering operations at Colombo is conducted below with the intention of identification of most appropriate development options.

3.1.1 Strengths

- **Geographic location of Colombo Port.**

  Colombo Port is located in the middle of east-west shipping route, which is a strategic location that can be used to attract more ships due to the option of bunkering during the middle of the voyage enabling ships to carry more cargo or to save energy by reducing bunker volumes onboard without deviating from the shipping route.

- **Local oil Refinery and pipeline connectivity.**

  Presence of the oil refinery and pipeline connectivity to the Colombo port enables to produce fuel at the refinery and transfer to the port.

- **Accredited Laboratory facilities to conduct petroleum fuel testing.**

  Accredited laboratory facilities and well experienced technical staff presence in Colombo is a very important factor for bunkering activities as fuel testing to verify the compliance with specifications is an essential activity.

- **Well established and experienced Bunker Operators.**

  There are many well established bunker operators at the Colombo port who have well educated and experienced workforce which is very important to successful implementation of new improvements. Some of the present workforce in these bunkering companies have earlier worked in the National Oil Company (CPC) prior to privatization of CPC's bunkering business in year 2002.

- **Government Policies favorable to develop bunkering business.**

  Government of Sri Lanka (GOSL) has made a policy decision to become the premier maritime and economic hub in the Indian Ocean. Ship bunkering is a key service that a maritime hub must possess to attract ships. Hence, it would be possible to get the support of the government towards development of bunkering business at Colombo Port.

- **Presence of unutilized Natural Gas reserves in the country.**
  Exploration activities have confirmed presence of natural gas reserves in the Mannar basin of Sri Lankan waters. Upon commercial exploitation of natural gas in Sri Lanka, it will be a very attractive option for bunkering considering the new regulatory requirements to reduce Sulphur content and IMO's focus towards cleaner fuels. It is also possible to produce Methanol from natural gas.

3.1.2 Weaknesses

- **Lack of infrastructure facilities related to bunker fuel.**
  There is only very limited capacity for storage of multiple grades of fuel in Colombo and there are no separate pipelines for different grades of fuel oil. All the bunker operators share the common user facilities available at the Colombo Port. This gives rise to additional operational requirements to avoid issues such as compatibility and stability of fuel oil which can occur due to mixing of different incompatible fuel oil batches.

- **High bunker fuel price.**
  Due to the high costs associated with the importation, the bunker fuel price at Colombo is not that attractive compared to other ports in the region. Small importation quantities due to lack of storage facilities and limitations in tanker berthing facilities also affect the cost as it is expensive than to import large parcel sizes.

- **Lack of other services related to shipping.**
  Lack of Port reception facilities at Colombo is a weakness that affect the attractiveness of Colombo, which also affect the bunkering business. If such facilities can be improved, it will help to attract more ships to the Colombo Port, which will increase the potential to grow the bunkering business too.

- **Lack of modern and high capacity processing units at the local oil refinery.**
  The Sapugaskanda refinery, which is the only oil refinery in Sri Lanka, is not currently capable of producing 0.5% m/m VLSFO as a straight run product to cater the new IMO

Sulphur regulation. This refinery is around fifty years old and it does not possess modern processing units. At the current configuration, the Sulphur level of produced fuel oil is 2.0% m/m.

- **Lack of finance**

  Sri Lanka being a developing country, it is extremely difficult to afford high investments that are required to introduce new types of fuel such as LNG/NG.

- **Lack of experience/ knowhow**

  Sri Lanka still lacks the experience or knowhow in handling new fuel types such as VLSFO and NG/LNG.

3.1.3 Opportunities

- **Offshore bunkering to ships that sail in east-west shipping route.**

  It is possible to develop offshore bunkering business to serve the large number of ships that sail in the east-west shipping route.

- **Upgrading/modification of local refinery to produce new fuel grades.**

  It is possible to produce 0.5 % m/m VLSFO by blending with middle distillate products as done in other modern refineries after certain modifications to processing units. It is also possible to use the existing pipelines connecting with Colombo port to transfer the fuel. However, its viability is very low when the price difference between VLSFO and 3.5 % HSFO.

  Switching to very low Sulphur crude oil is another alternative. However, this also requires certain modifications to the refinery and it can be an expensive solution considering the price of very low Sulphur crude oil and cost of modifications.

- **Introduction of Natural Gas**

  Production of Natural Gas (NG) from local reserves or importation of LNG provides the opportunity to introduce LNG/NG option for bunkering which fulfills new Sulphur regulation requirement. Recent discoveries of offshore natural gas reserves within Sri Lankan waters is a very encouraging reason to initiate LNG/NG related activities. The new IMO 2020 Sulphur regulation will be an incentive for the industry to switch to LNG powered ships.

- **Introduction of Methanol**

  According to fourth IMO GHG study Methanol is the fourth most significant fuel used during the period 2012-2018 (IMO, 2020). Hence, Methanol is another option that should be looked into as it can be produced from natural gas, which is a very clean fuel. Conversion of LNG to Methanol will eliminate the cryogenic operations and hence eliminate the requirement of developing costly infrastructure facilities and enable to use existing infrastructure used for fuel oil. However, the overall GHG emission will be higher compared to that of natural gas since the additional processing of LNG to methanol requires additional energy and emits additional CO_2, so that producing methanol from natural gas is worse in terms of climate impact than LNG itself.

- **Increase of world shipping fleet**

  Predicted increase in world shipping fleet is an encouraging factor to develop bunkering business. Hence there is a promising opportunity to expand the existing infrastructure facilities for bunkering.

3.1.4 Threats

- **Changes in International Regulations**

  Changes in International regulations such as IMO 2020 Sulphur cap has given rise to many challenges to bunkering business due to drastic change in fuel specifications. Further changes in regulations are expected in future with respect to reduction of GHG emission from shipping that could be challenging to comply with.

  The Initial IMO Strategy on Reduction of GHG Emissions from Ships introduced in 2018 aims at reduction of “CO2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008” and “to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008” (IMO, 2020).

However, recent studies indicates the requirement of implementation of new regulations to achieve these targets as it would not be possible to achieve it with the present situation.

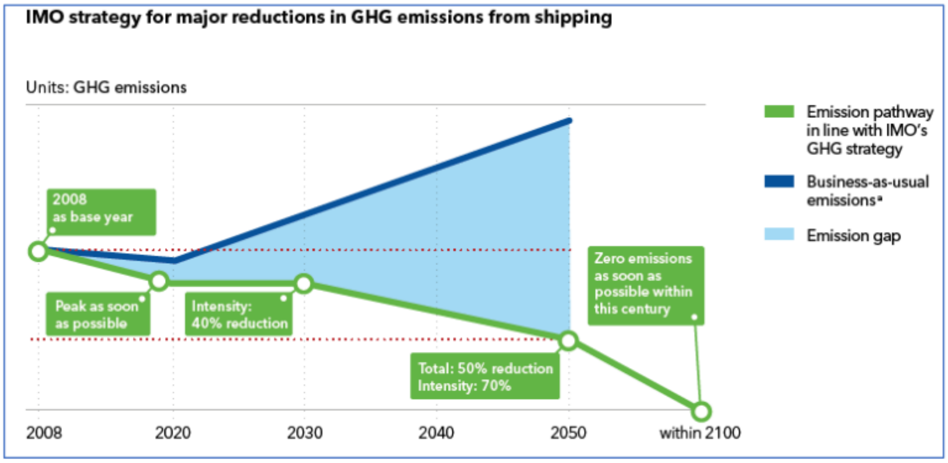

Figure 12. IMO strategy for major reductions in GHG emissions from shipping. From " Maritime Forecast to 2050: Energy Transition Outlook 2019", by DNV GL, 2019, p.24., Copyright 2019 DNV GL.

The recent Fourth IMO GHG study indicates requirement of considering life cycle GHG emission of fuel rather than CO_2 emission by onboard combustion for the EEDI related regulations (IMO, 2020).

Change of regulations can have a direct impact on the demand for bunker fuel and hence it has to be considered when investing for infrastructure development.

- **Issues with Stability and Compatibility of Different batches of Fuel Oil.**

  The most recent change in IMO Sulphur regulation demanding VLSFO with 0.50 % Sulphur has given rise to many issues as it is a blended product with ratios that are not familiar to the industry. VLSFO are normally produced by blending middle distillates with fuel oil (which can be from various sources and produced from different types of crude oil) in higher blending ratios. This increase the probability to cause issues with respect to stability and compatibility of fuel oil that is not suitable to use for ship operations.

- **High competition from other Ports**

  Bunkering companies in Colombo Port has to compete with other ports in the region including the Hambanthota Port in Sri Lanka operated by a Chinese company.

3.2 Development Options

3.2.1 Local Refinery

Based on the *SWOT analysis* and feedback received from bunker operators, it can be identified that the main weakness or barrier to develop bunkering business in Colombo is the high bunker oil prices which is due to the fact that bunker fuel is primarily imported at the moment making it impossible to compete with the prices at bunkering hubs such as Singapore and Fujairah. Hence, it is evident that development of the local oil refinery or setting up of a new oil refinery is required to make bunker fuel available at a competitive price in Colombo. It is to be noted that Singapore is being able to perform well as a bunkering and oil-trading hub due to the presence of high capacity modern oil refineries. Singapore alone currently accounts for 22% of world bunkering sales (IRENA, 2019).

Even though there had been proposals to modernize and expand the Sapugaskanda oil refinery, it has been held up for more than a decade due to non-availability of finance. Hence, it was intended to discuss the other options to develop the bunkering business at Colombo.

3.2.2 Expansion of Capacity at the JCT oil bank

According to JCT Ltd., JCT oil bank reached its maximum capacity in 2018 by handling around 600,000 MT of bunker fuel. There is an immediate requirement to increase the storage capacity of JCT oil bank and construction of pipelines dedicated to different fuel oil grades of VLSFO and HSFO. Based on the aerial images it can be observed that

Figure 13. Possibility of expansion of storage capacity at JCT oil bank.

there is space to construct more storage tanks at the JCT oil bank premises in Bloemendhal.

The largest existing tank in this terminal is 7,834 m^3. Hence, with sharing of existing bund wall facilities, firefighting facilities and relocation of some existing structures it would be possible to construct at least two more 5500 m^3 capacity storage tanks complying with the fire and safety regulations as indicated in the Figure 12 above in red squares. This would increase the total storage capacity of the fuel oil which is the main type of fuel handled in the facility to 37,771 m^3, which is an increase of 41% of capacity for fuel oil and increase of 28% for the total capacity. Together with two new pipelines, connecting to the port this would greatly improve the operational flexibility of the JCT oil bank. It would be able to conduct simultaneous operations of receiving and discharging of all grades of bunker oil with this arrangement. It could assume that it would easily increase the total throughput per annum by 40% i.e. to around 840,000MT/annum subject to uninterrupted receiving and discharging. Approximate capital expenditure (CAPEX) for the above will be around USD 3 million. A detailed estimate on CAPEX is given in Appendix 3. It is required to conduct further evaluation of the facility to decide exact possible tank capacities and CAPEX, which is not possible in this study due to the limitations on time and accessibility to site.

According to the present world fleet, container fleet and ships in order fitted with scrubbers it can assume that demand for HSFO will increase in future making the relevant investments viable. More details on the above is provided in section 4.2.1.1.

3.2.3 LNG Bunkering

"LNG as an alternative fuel for Shipping has been increasingly adopted as a strategy for environmental compliance, either sailing or at port. With an immediate significant impact on the reduction of Sulphur Oxides emissions (SOx), Particulate Matter (PM), and also of Nitrogen Oxides (NOx) the motivations for the use of LNG as fuel in maritime transport are today highly favoured by a relevant multi-layered regulatory frame" (EMSA,2018). LNG combustion emits almost zero SOx and very little amount of NOx. Hence, LNG has been identified as a great solution to comply with SOx and NOx related regulations in SOx and NOx emission control areas and globally after implementation of IMO 2020 regulation. Number of ships capable of using LNG are also increasing because of the above. According to data available in Clarkson Research, as at August 2020, there are 574 total ships capable of using LNG in the world, which accounts for 3.15% of gross tonnage of the world fleet (refer Appendix 5) and the number of LNG capable ships in order is 364 which represents 8.56% of total ships in order. This is also equal to around 20% of total gross tonnage of ships in order (refer Appendix 6).

However further analysis on container ships powered by LNG indicates a limited potential for LNG in near future in Colombo. This analysis is provided in section 4.2.1.1. According to Balcombe et al (2019), “current LNG powered vessels are mainly operate in Europe due to the expansive ECAs, and most new vessels are planned in Europe and North America due to emissions regulations and underlying fuel prices”.

With respect to GHG emission there is about 25% reduction in CO_2 emission by LNG combustion in comparison to combustion of fuel oil. However, due to leakage of natural gas (methane) throughout the supply chain and methane slip in engines, the overall reduction in GHG emission achievable by switching from fuel oil to LNG is about 10% (EMSA, 2018, IRENA, 2019). According to Baresic et al (2018), “there is a very uncertain future demand for LNG as a marine fuel over the next 10 years. On the one hand, it is an option for complying with the 2020 sulphur cap, but as it cannot enable the GHG reductions that have been committed to in the IMO’s initial strategy for GHG reduction and the Paris temperature goals more generally, it is clear its role can only be transient and not transitional.”

The recent fourth IMO GHG study also indicates 150% increase in methane emissions from shipping during 2012-2018 due to increase use of LNG by ships which are not equipped with engines that minimize methane slip. Hence, it has been recommended to include methane in future regulations as the current focus is only on CO_2 emissions under ship Energy Efficiency Design Index (EEDI) related regulations. (IMO, 2020). To minimize overall GHG emission, it is required to control emission of methane throughout the supply chain, which includes storage and bunkering activities.

Considering the fact that there are unutilized local natural gas reserves and the increase of LNG capable ships, it is prudent to introduce LNG to the country in small scale in near future, which would enable to develop the knowhow in LNG/NG handling in the country. Flash point of LNG is -175^0C, which is extremely low compared to oil fuel and even much lower than other low flashpoint fuels such as methanol (12ºC) or even ethanol (17ºC) (EMSA,2018). Hazards associated with LNG are extremely complex. Hence, it is required to follow extremely stringent safety measures when storing and handling LNG. It is also not possible to store LNG for long periods without consumption due to continuous generation of boil of gas. Natural gas (primarily consisting of methane) is cooled below -162^{0}C at atmospheric pressure to maintain in liquid form during storage and transportation as the liquid state consumes 600 times less volume than the gaseous state. Hence, LNG requires special extremely expensive equipment and facilities suitable for cryogenic operations.

Introduction of LNG bunkering requires a comprehensive risk assessment complying with international guidelines such as ISO/TS 18683 to ensure that risks to people and the environment have been eliminated up to the acceptable limits, and if not, mitigated as necessary, which includes defining of required safety zone and security zone around the bunkering operation. It would be required to conduct Quantitative Risk Assessment (QRA) in addition to a Qualitative Risk Assessment (QualRA) depending on the site-specific conditions and the proposal (EMSA, 2018).

Given below is a graphical representation of different supply arrangements used for LNG bunkering when LNG is delivered to port by sea.

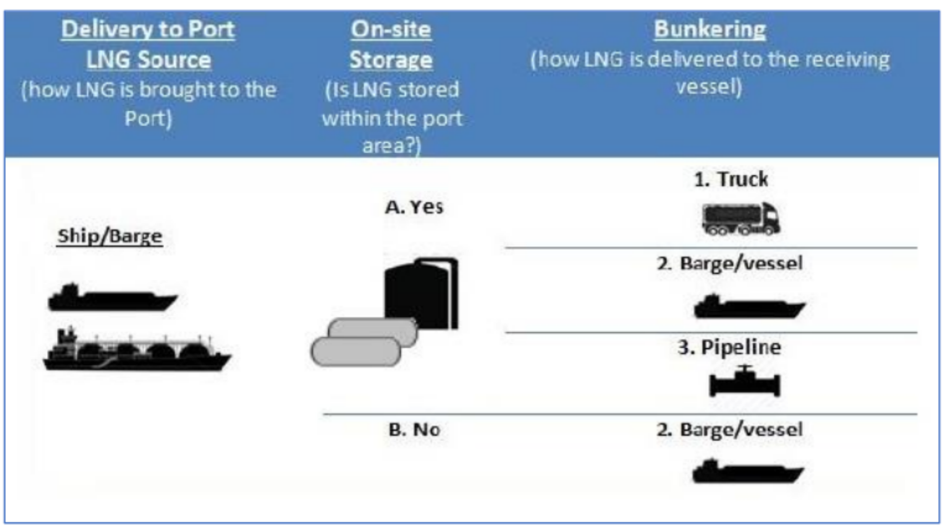

Figure 14. LNG fuel supply options inside the port area. Adapted from “Guidance on LNG Bunkering to Port Authorities and Administrations” by EMSA, 2018, p.44.

Decision of having on-site storage depends on the availability of land with required safety zone, which is beyond the scope of this study to identify. However, considering the highly congested nature of Colombo port it would be extremely difficult to find a suitable location. If it is not possible to have on-site storage tanks, it may be possible to have a small capacity floating regasification and storage barge (FSRB) which provides a lot of flexibility in terms of the location.

Alternatively, it is also possible to go for LNG ISO containers (LNG portable tanks), subject to the condition that receiving vessels are equipped with necessary connections to use LNG from these units. Special precautions will be required to differentiate the handling of these containerized units from other containerized cargo. These units can be directly supplied to ships needing LNG by cranes and transfer of LNG is done within the ship (EMSA, 2018).

This option can only serve ships equipped with necessary connections and it may not be an attractive solution compared to FSRB, with respect to the delivery rate and time consumption as it will have to utilize cargo-handling cranes for bunkering resulting in delays for cargo handling. However, capital expenditure for FSRB will be comparatively very high where smallest available FSRB (7500 m^3 – 15,000 m^3) would cost around USD 30-40 million and FSRB of 50,000 m^3 capacity would cost around USD 120 million (Wärtsilä, 2018). The required storage size depends on the send out rate and possible frequency of replenishment of stocks. LNG Storage capacity of 15,000m^3 (equal to 7,000 MT) would be sufficient to cater around 90,000 MT per annum considering stock replenishments in three weekly intervals by 5000MT parcels. LNG Storage capacity of 50,000m^3 (equal to 23,500 MT) would be sufficient to cater around 300,000 MT per annum considering stock replenishments in three weekly intervals by 40,000MT parcels.

4. CHAPTER 4 – Multi Criteria Decision Analysis

4.1 Scenarios Analysis for different options for bunkering

Proposed scenarios with different operational and development options for bunkering in Colombo for the period 2020-2030 are discussed below.

Scenario 1

Scenario 1 is taken as business as usual without any changes to operational procedures and infrastructure. (Storage capacity: 26,000 MT Fuel oil, 10,500 MT MGO). With the current arrangement fuel delivery, consist of 75% of VLSFO and 25% MGO. Expected maximum annual throughput is 510,000 MT which is 15% less than the capacity due to non presence of HSFO.

Scenario 2

Assumes introduction of additional operational procedures without change in infrastructure to deliver HSFO for the existing scrubber fitted ships. (Storage capacity: 26,000 MT Fuel oil, 10,500 MT MGO). Since around 90% of the ships call at Colombo port is Container ships and the current composition of container fleet consists of 15% (Gross tonnage) scrubber fitted ships potential for HSFO is assumed as 15%. It is further assumed that 15% demand for MGO. Expected maximum annual throughput is 600,000 MT. (Delivery Mix: VLSFO 70%, HSFO 15%, MGO 15%)

Scenario 3

Assumes expansion of infrastructure to cater HSFO by construction of two nos 5000 MT storage tanks and two 12-inch diameter dedicated pipelines. Expected CAPEX is USD 3 million. (Storage capacity: 36,000 MT Fuel oil, 10,500 MT MGO). Increase in scrubber fitted ships are expected to result in increase of demand for HSFO. Expected maximum annual throughput is 840,000 MT. (Delivery Mix: VLSFO 60%, HSFO 30%, MGO 10%)

Scenario 4

Assumes expansion of infrastructure to cater HSFO by construction of two nos. 5000 MT storage tanks and dedicated pipelines. Expected CAPEX is USD 3 million. (Storage capacity: 36,000 MT Fuel oil, 10,500 MT MGO). Introduction of LNG in small scale to cater 10 % of total demand. CAPEX on infrastructure development for LNG is assumed to be around USD 40 million. Expected maximum annual throughput is 840,000 MT oil fuel + 93,330 MT LNG. (Delivery Mix: VLSFO 55%, HSFO 25%, LNG 10%, MGO 10%)

Scenario 5

Assumes expansion of infrastructure to cater HSFO by construction of two nos. 5000 MT storage tanks and dedicated pipelines. Expected CAPEX is USD 3 million. (Storage capacity: 36,000 MT Fuel oil, 10,500 MT MGO) and introduction of LNG in small scale to cater 10 % of total demand. CAPEX on infrastructure development for LNG is assumed to be between USD 40 million. It is also assumed introduction of Methanol using the existing infrastructure to replace a fair share of MGO. Share of 5% Methanol is assumed for this case. Expected maximum annual throughput is 840,000 MT oil fuel + 93,330 MT LNG. (Delivery Mix: VLSFO 55%, HSFO 25%, LNG 10%, MGO 5%, Methanol 5%).

Scenario 6

Assumes expansion of infrastructure to cater HSFO by construction of two nos. 5000 MT storage tanks and dedicated pipeline. Expected CAPEX is USD 3 million. (Storage capacity: 36,000 MT Fuel oil, 10,500 MT MGO). Also assumes introduction of Methanol using the existing infrastructure to replace a fair share of MGO and no LNG. Allocation of additional tanks for HSFO to cater increase of demand due to increase of scrubber fitted ships. Share of 5% Methanol is assumed for this case. Expected maximum annual throughput is 840,000 MT. (Delivery Mix: VLSFO 60%, HSFO 30%, LNG 0 %, MGO 5%, Methanol 5%).

Scenario 7

Assumes no investment on oil fuel infrastructure (Storage capacity remains at 26,000 MT Fuel oil, 10,500 MT MGO) but invest for LNG to cater 35% of total demand. CAPEX for medium scale LNG bunkering facilities is assumed to be around USD 120 million. Expected maximum annual throughput is 510,000 MT oil fuel + 324,545 MT LNG (Delivery Mix: VLSFO 55%, HSFO 0%, LNG 35 %, MGO 10%).

Scenario 8

Assumes expansion of infrastructure to cater HSFO by construction of two nos. 5000 MT storage tanks and dedicated pipelines. Expected CAPEX is USD 3 million. (Storage capacity: 36,000 MT Fuel oil, 10,500 MT MGO) and introduction of LNG to cater around 30 % of total demand. CAPEX on infrastructure development for LNG is assumed to be around USD 120 million. Expected maximum annual throughput is 840,000 MT oil fuel + 324,545 MT LNG (Delivery Mix: VLSFO 50%, HSFO 20%, LNG 28 %, MGO 5%).

4.2 Criteria for Decision Analysis

Following multiple criteria were considered for the decision analysis for selection of appropriate development/ operation option for Colombo Port in future.

- Future fuel mix
- Future regulations
- Availability of fuel
- Investment cost on Infrastructure
- Technical Know-how
- Throughput capacity
- Operational complexity

4.2.1 Fuel Mix of Future shipping fleet

Future fuel mix should be the main factor to consider when planning for future developments in bunker industry. Next section contains a literature review on the fuel mix projected by various parties.

Global Marine Fuel Trends 2030 (Argyros, Raucci, Sabio & Smith, 2014) provides very comprehensive projections under three scenarios up to year 2030 indicating fuel mix for different vessel types. These scenarios have been developed based on factors such as trade growth, oil & gas prices, regulations and availability of bio energy. The three scenarios considered and most relevant assumptions are as follows:

- **Status Quo:** "Business as usual, economic growth at the current rate, short term solutions, rapid regulatory change. In this scenario, shipping will develop but in a controlled rate" – Assumes implementation of 0.5% Sulphur regulation in 2025, $40/t carbon price from 2030.
- **Global Commons**: "More economic growth, more international cooperation, regulation harmonization, international trade agreements, emphasis on environmental protection and climate change, expansion of globalization. Shipping will be favored in this scenario." - Assumes implementation of 0.5% Sulphur regulation in 2025. Global carbon price introduced in 2030, no ECAs
- **Competing Nations**: "Dogmatic approaches and regulatory fragmentation, protectionism, local production and consumption, trade blocks, brake in globalisation.

Shipping will be negatively impacted in this scenario." - Assumes implementation of 0.5% Sulphur regulation in 2030, no carbon price.

Given below is the fuel mix projection for the 'Status Quo' scenario, which is more relevant to present conditions.

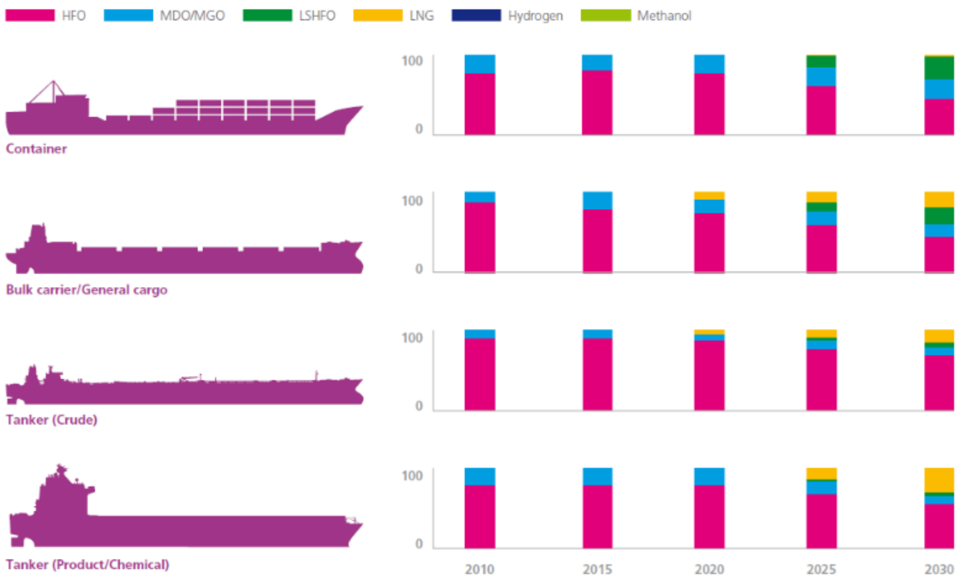

Figure 15. Fuel mix forecast for global fleet (%). From "Global Marine Fuel Trends 2030" by D. Argyros, C. Raucci, N. Sabio, T. Smith, 2014. Copyright 2014 Lloyd's Register and University College London.

It also indicated fuel mix for the all types of ships in 2030 as 48% HSFO, 22% VLSFO, 19% MGO/MDO and 12% LNG. However, it can be noted that this forecast has not considered the IMO 2020 as this study has been done prior to year 2014. IMO confirmed the 2020 0.5% Sulphur regulation in year 2016 during its Marine Environment Protection Committee (MEPC), meeting for its 70th session in London. "The date of 2020 was agreed in amendments adopted in 2008. When those amendments were adopted, it was also agreed that a review should be undertaken by 2018 in order to assess whether sufficient compliant fuel oil would be available to meet the 2020 date. If not, the date could be deferred to 2025. That review was completed in 2016 and submitted to MEPC 70. The review concluded that sufficient compliant fuel oil would be available to meet the fuel oil requirements" (IMO, 2016 b). This study has considered the implementation of new Sulphur regulation in 2025 under the status quo scenario. However, it provides a good insight about the fuel types demanded by the container fleet.

The Third IMO GHG study provides two forecasted fuel mix scenarios considering the implementation of IMO 0.5% Sulphur regulation on 1 January 2020.

Table 7. Fuel mix scenarios used for Third IMO GHG Study. From "Third IMO GHG Study 2014", 2014, by IMO, p.287.

High LNG/extra ECAs case	LNG share	Distillates and LSHFO*	HFO
2012	0%	15%	85%
2020	10%	30%	60%
2030	15%	35%	50%
2050	25%	35%	40%

Low LNG/constant ECAs case	LNG share	Distillates and LSHFO*	HFO
2012	0%	15%	85%
2020	2%	25%	73%
2030	4%	25%	71%
2050	8%	25%	67%

* Sulphur content of 1% in 2012 and 0.5% from 2020.

The first scenario of high LNG case, is based on the assumption of establishment of extra emission control areas (ECAs) and the second scenario for low LNG case is based on the assumption that no extra ECAs will be established in the future. Both these scenarios project higher percentage for HSFO than VLSFO in 2020 (IMO, 2014).

Fourth IMO GHG Study indicates share of three most important fuel types consumed during 2012- 2018. Accordingly, the marine fuel usage in year 2018 consist of around 79% HFO, around 4% LNG, and around 16.5% MDO. It also indicates that fourth most significant fuel as Methanol with approximate consumption of 130,000 tonnes in 2018. However, this is even less than 0.055% (IMO, 2020).

Hence, the above scenarios in third IMO GHG study also does not reflect the actual condition as at 2020, especially with respect to the share of HSFO and VLSFO. Actual share of VLSFO has become higher than the share of HSFO after the implementation of IMO 2020 Sulphur regulation owing to the limited number of scrubber fitted ships. With respect to LNG share, the scenario for 'Low LNG/constant ECA case" is somewhat closer to the actual condition as at 2020. However, it is to be noted that, majority of actual LNG consumption mentioned above is originating from boil-off gas used by tankers carrying LNG as cargo rather than sale of LNG to ships to be used as fuel (IMO, 2020).

Given below is a projected bunker demand for different fuel types in the future as done by Alfa Laval.

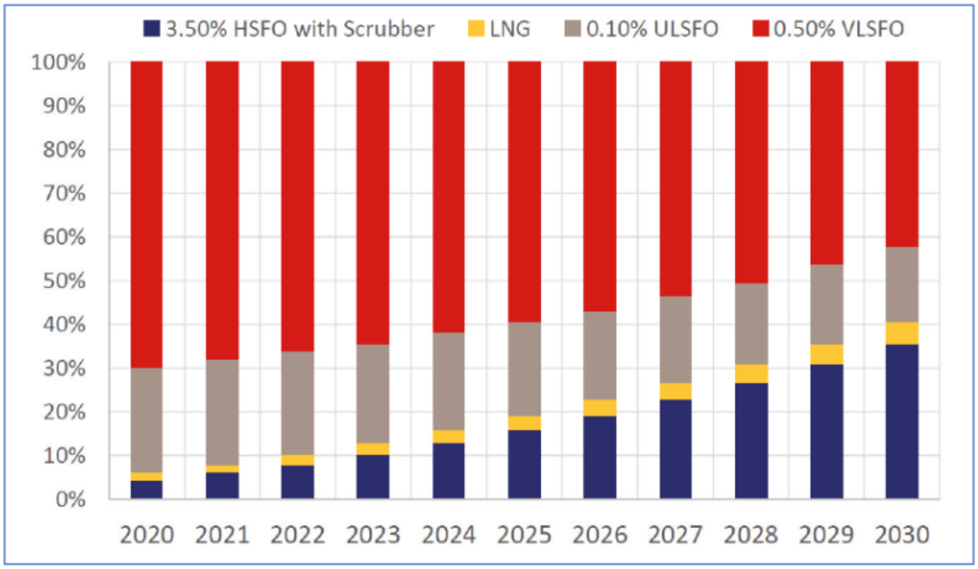

Figure 16. Projected bunker demand for different fuel types up to 2030. From "The Alfa Laval Adaptive Fuel Line Blue Book", 2018. P.7. Copyright 2018 by Alfa Laval.

This projection done in 2018 matches much better with the actual fuel mix at present with respect to the VLSFO and LNG. It indicates 70% VLSFO, 2% LNG, 4% HSFO, and 24% ULSFO for 2020. However, it does not indicate MGO/MDO in the fuel mix. The projected LNG share is very close to the 'Low LNG/constant ECA' scenario of the Third IMO GHG study with around 5% in 2030. This projection also considers increase of scrubber fitted ships resulting in increase in share of HSFO up to 35% by 2030 and decrease of VLSFO share to about 43% in 2030.

Maritime Forecast to 2050: Energy Transition Outlook 2019 by DNV GL presents three pathways for future marine fuel mix. Two pathways are to achieve IMO ambitions on reduction of GHG emissions based on design requirements and the other on operational requirements. The third pathway is based on current policies. "In all three pathways modelled, liquefied methane ends up dominating the fuel mix (40%–80% in 2050), but the primary energy source of the methane varies between fossil, biomass and other renewables. Carbon-neutral fuels need to supply 30%–40% of the total energy for international shipping in mid-century if the IMO's ambitions for reducing GHGs are to be achieved" (DNV GL, 2019).

The IMO ambitions operational requirement pathway, indicates LNG to initially capture a large share of the fuel mix, due to gradually stricter operational requirements on GHG emissions and by 2050 the fuel mix contains 70% fossil LNG, 13% carbon-neutral methane and 17% other carbon-neutral fuels while liquid fossil fuels share almost become zero (DNV GL, 2019).

In the Current policies pathway, no further policies are expected resulting in transition to other fuels. The energy mix in 2050 will be 93% based on fossil fuels with 50% LNG and 43% liquid fuels (DNV GL, 2019).

Both the above pathways depend heavily on fossil LNG, which is too ambitious due to the lack of advantage with respect to the overall GHG emission by using LNG and focus on reduction of GHG emissions by IMO in future.

Given below is the projected the fuel mix for 2018-2050 period for simulated IMO ambitions pathway with main focus on design requirements.

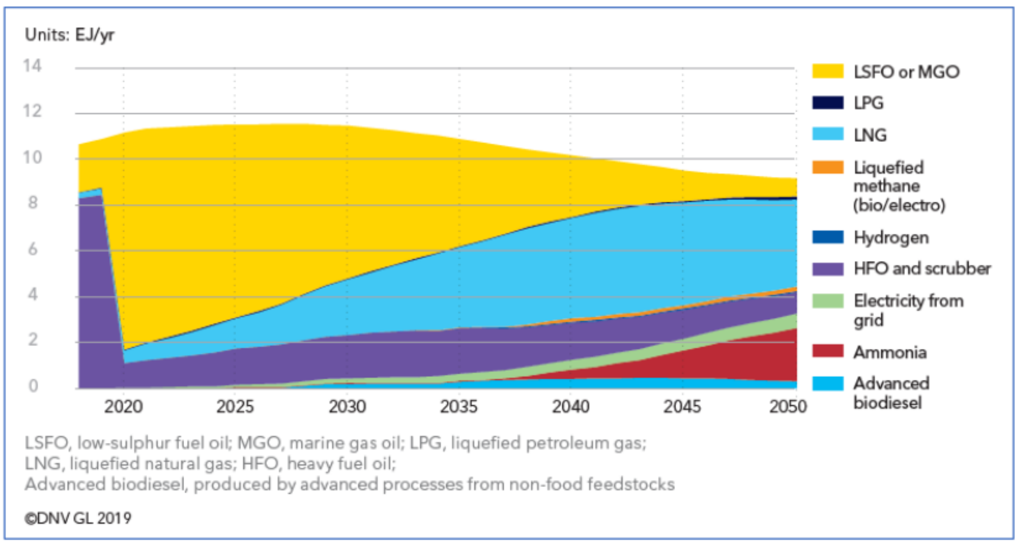

Figure 17. Fuel mix for 2019-2050 period for simulated IMO ambitions pathway. From "Maritime Forecast to 2050: Energy Transition Outlook 2019", by DNV GL, 2019, p.93. Copyright 2019 by DNV GL.

It indicates around 10% of HSFO, around 4% of LNG and around 86% of LSFO and MGO for year 2020. It also indicates very small share for LPG and use of electricity from grid in 2020. For 2030, it has projected increase of HSFO share to around 18%, decrease of LSFO+MGO share to around 55%, increase of LNG share to around 20%, electricity from grid around 2.5%, advanced bio diesel 2% ,very small amounts of LPG and Ammonia.

Approximate fuel mix in 2050 as projected by DNV GL as follows: LNG 41%, HSFO 10%, VLSFO+MGO 9%, Ammonia 25%, electricity from grid 6%, advanced bio diesel 4%.

However, with respect to the high share of Ammonia in 2050, DNV GL indicates significant uncertainties on costs and availability of NH_3 relative to other fuels. “The availability of new fuels will experience the same chicken-and-egg problem that we have seen with LNG. Without any infrastructure and distribution, it is difficult for ship owners to commit to a new fuel, but suppliers will not develop the infrastructure before they are certain of demand” (DNV-GL, 2019).

4.2.1.1 Projection of Fuel mix of the Ships calling at Colombo in 2030

Around 90% of the ships calling at the Colombo port are container ships and it could assume that Colombo port will continue to grow as a container transshipment hub in the future. According to the fuel mix projection for Container vessels done in Global Marine Fuel Trends 2030 as indicated in the Figure 14 above, it can be expected that future bunker fuel demand at Colombo port will mainly consist of HSFO, VLSFO, MGO with a very small potential for LNG.

Summary of projections for VLSFO, HSFO, MGO & LNG discussed earlier for 2030 world fleet are indicated below:

Table 8. Projected VLSFO,HSFO, Distillate & LNG share for 2030 under various studies

Projection study	VLSFO	MGO/ MDO	HSFO	LNG
Global Maritime Fuel Trends 2030 (Status Quo), 2014	22%	19%	48%	12%
3rd IMO GHG Study (High LNG/ Extra ECA), 2014	35%		50%	15%
3rd IMO GHG Study (Low LNG/ Const. ECA), 2014	25%		71%	4%
Alfa Laval, 2018	43%		35%	5%
DNV-GL (IMO ambitions pathway with main focus on design requirements), 2019	55%		18%	20%

According to Clarksons Research, the present container fleet contains only 07 (0.1 % of total fleet) LNG capable ships and there are 33 in the order book, which represents 10.2% of total order book. With respect to the total order book TEU, it represents 22.3%. The average age of the current container fleet is 12.8 years and hence, the potential for LNG in the next ten years is somewhat limited. However, at present there are 574 total ships capable of using LNG in the world, which accounts for 3.15% of gross tonnage of the world fleet (refer Appendix 5) and the number of LNG capable ships in order is 364 which represents 8.56% of total ships in order. This is also equal around 20% of total gross tonnage of ships in order (refer Appendix 6). Considering the above and projections discussed in section 4.2.1, the potential share for LNG is taken as 4% for Colombo in 2030.

Before the IMO 2020, share of HSFO bunker delivery at Colombo has been around 88%. After IMO 2020, HSFO has been discontinued due to practical difficulties and the replacing fuel VLSFO currently accounts only for about 75% of total bunker delivery. The decline of share of 13% for fuel oil could be due to the non-presence of HSFO demanded by ships fitted with scrubbers.

According to Clarkson Research, as at August 2020, there are total of 3,295 ships fitted with SOx scrubbers, which is equal to 3.32% in number of ships but represents 17.55% of gross tonnage of world fleet (refer Appendix 4). The total number of container ships equipped and being equipped with SOx scrubbers as at August 2020 is 792, which is equal to 15% of total container fleet and represents 29% of total fleet TEU. Number of container ships in order book with SOx scrubbers is 113 (35% of order book) which represents 56% of total TEU of order book (refer Appendix 7). Hence, it can be assumed that number and gross tonnage of container vessels equipped with SOx scrubbers in operation will further increase in future. The gross tonnage of ships is a more appropriate indicator of potential fuel consumption than the number of ships as fuel consumption depends on the size of ship.

Considering the above and projections discussed in section 4.2.1, the potential share for total VLSFO and HSFO is taken as 85% with 50% for VLSFO and 35% for HSFO respectively in 2030. The balance 10% is expected to be MGO similar to the pre IMO 2020 era at Colombo. Fourth IMO GHG study indicates Methanol as the fourth most significant fuel consumed in the period 2012-2018 with around 0.06% share (IMO, 2020). Methanol also complies with the new IMO Sulphur regulation to use directly as a ship fuel similar to LNG but does not involve cryogenic operations as LNG and also requires less stringent safety procedures compared to LNG. Hence, Methanol is proposed with a share of 1% for 2030 in Colombo.

Table 9. Projected bunker fuel mix for Colombo in 2030

Fuel	VLSFO	HSFO	MGO	LNG	Methanol
Share % (2030)	50%	35%	10%	4%	1%

With respect to the fuel mix of the scenarios considered for this study, dissimilarity between the projected fuel mix in 2030 is calculated by obtaining the square root of the summation of squares of dissimilarity of share for each fuel.

$$Dissimilarity\ to\ the\ projected\ fuel\ mix\ (D_j) = \sqrt{\sum_{i=1}^{5}(s_{ij} - p_i)^2}\ ,\ j=1, 2, 3, \ldots, 8$$

s_{ij} is the share(%) of fuel i for the scenario j and p_i is the share of same fuel i in the projected fuel mix.

Table 10. Dissimilarity between the future fuel mix and the scenarios considered for 2030

Scenario	VLSFO %	HSFO %	MGO %	LNG %	Methanol %	Dissimilarity with Future Fuel Mix (D_j)
1	75%	0%	25%	0%	0%	48%
2	70%	15%	15%	0%	0%	30%
3	60%	30%	10%	0%	0%	13%
4	55%	25%	10%	10%	0%	14%
5	55%	25%	5%	10%	5%	13%
6	60%	30%	5%	0%	5%	13%
7	55%	0%	10%	35%	0%	47%
8	50%	22%	5%	28%	0%	27%
Projected fuel mix	50%	35%	10%	4%	1%	

4.2.1.2 Projection of Fuel mix of the Ships calling at Colombo in 2050

The average age of the container fleet is 12.8 years and considering the fact that ships will normally engage in trading for 20-30 years it can be noted that all the ships in current fleet including ships in order will be retired by 2050. Hence, the fuel mix of the shipping fleet in 2050 will depend on the regulatory requirements and energy cost after 2030. As discussed earlier the primary focus of future regulations would be the reduction of GHG emission. It is expected to switch over to carbon neutral energy sources and the relevant technologies are being developed. Hence, it is extremely difficult to predict about the future fuel mix. Therefore, following fuel mix is proposed for Colombo in 2050 based on the projection of DNV GL discussed earlier and local conditions.

Table 11.Projected bunker fuel mix for Colombo in 2050

Fuel	VLSFO+ MGO	HSFO	LNG	Ammonia	Electricity from grid
Share % (2050)	15%	15%	40%	25%	5%

DNV GL has projected LNG 41%, HSFO 10%, VLSFO+MGO 9%, Ammonia 25%, electricity from grid 6%, advanced bio diesel 4% for 2050. Even though there is no significant advantage of LNG with respect to GHG emission, it is a much better option with respect to reduction of other emissions that are harmful to health and environment. It is also expected that new technologies will be developed to minimize the methane slip from ships in future. Further, considering the fact that there are natural gas reserves in Sri Lanka and it will be exploited at that time a share of 35% is proposed. It may be possible to couple LNG facilities with power generation to serve ships requiring electricity power, which will also reduce the issues associated with boil off gas generation during storage. Hence, electricity from grid is proposed as 5%. Bio fuel is not considered for the fuel mix considering the possible lack of availability. Balance is proportionately distributed between HSFO and VLSFO+MGO.

It was decided not to conduct TOPSIS analysis for 2050 due lack of information and too much uncertainty associated with attributes such as fuel availability, technical knowhow, and CAPEX requirement on proposed new fuel such as Ammonia for which technological developments are still in progress. It was noted that all these attributes could change rapidly as the relevant technologies are developed to suit commercial application.

4.2.2 Future Regulations

Since reduction of GHG emission will be the main focus in near future, it was intended to obtain the lifecycle GHG emission per a unit of fuel (mix) under each scenario which provides an indication about the compliance with future regulation requirements. Lifecycle GHG emissions in gCO_2 equiv./MJ of fuel energy are as follows:

Methanol: 90, LNG: 80, HFO: 90 (Hansson, Månsson, Brynolf,& Grahn, 2019). Lifecycle GHG emission of MGO was assumed same as HFO.

The approximate Lifecycle GHG emissions in gCO_2 equiv. per MT of fuel were obtained by multiplying the above values with the relevant calorific values of the fuel in order to obtain mass based figures as the scenarios considered are in mass base. The calorific values of HSFO (40.4 MJ/kg), VLSFO (41.6 MJ/kg) and MGO (42.6 MJ/kg) were obtained from global average calorific values (integr8fuels, 2019) and values of Methanol (20 MJ/kg) and LNG (48.6 MJ/kg) were obtained from the data available in Engineering toolbox (2020).

Table 12. Lifecycle GHG emission of fuel considered for the scenarios

	VLSFO	HSFO	MGO	LNG	Methanol
Net Calorific value (MJ/kg)	41.6	40.4	42.6	48.6	20
Life cycle GWP100, CO_2 equ (g/MJ)	90	90	90	80	90
Approx. LCL CO_2 equ/kg of fuel(g/Kg)	3744	3636	3834	3888	1800
Approx. LCL CO_2 equ/kg of fuel (kg/MT)	3744	3636	3834	3888	1800

GHG emission per unit for each scenario is obtained by multiplying the share percentage of each fuel with relevant life cycle GHG emission per MT.

$$\textit{GHG emission per unit of fuel mix } (G_j) = = \sum_{i=1}^{5}(g_i \text{ x } s_{ij}) \ , \ \ j = 1,2,3,\ldots, 8$$

s_{ij} is the share(%) of fuel i for the scenario j and g_i is the relevant life cycle GHG emission (in kg) per MT of fuel i.

Table 13. Contribution to GHG emission per unit for the scenarios considered for 2030

Scenario	VLSFO %	HSFO %	MGO %	LNG %	Methanol %	Contribution to GHG emission per unit (Kg/MT)
1	75%	0%	25%	0%	0%	3,766.5
2	70%	15%	15%	0%	0%	3,741.3
3	60%	30%	10%	0%	0%	3,720.6
4	55%	25%	10%	10%	0%	3,740.4
5	55%	25%	5%	10%	5%	3,638.7
6	60%	30%	5%	0%	5%	3,618.9
7	55%	0%	10%	35%	0%	3,803.4
8	50%	22%	5%	28%	0%	3,952.3

4.2.3 Fuel Availability

Marks for Fuel availability for each fuel for 2030 were allocated considering availability through local production, requirement of importing and ease of sourcing.

Table 14. Marks allocation for availability of each fuel for 2030

Fuel	Fuel Availability	Marks	Description
VLSFO	Very Good	9	VLSFO is currently imported 100% and it is currently sourced from Singapore and Middle East where the availability is very good.
HSFO	Very Good	9	HSFO is produced at the local refinery and it is imported when the local supply is not sufficient. Hence availability is defined as very good. Maximum marks of 10 is not allocated here as there is always an imported portion.
MGO	Very Good	9	Availability of MGO is very good as it can be easily imported or even produced locally.
LNG	Moderate	7	LNG is available for importation in sufficient quantities. However availability is lower than that of fuel oil and MGO. Hence, availability is defined as moderate. There is a potential for the availability to reach excellent level in case of local exploitation in future.
Methanol	Very Poor	3	Use of Methanol for ships is extremely low at present and the availability in sufficient quantities is very limited.

Marks for fuel availability of fuel mix of each scenario (A_j) were obtained by summing up the products of fuel share and relevant fuel availability mark.

Fuel Availability (A_j) = = $\sum_{i=1}^{5}(a_i \text{ x } s_{ij})$, j =1,2,3,…, 8

s_{ij} is share(%) of fuel i for the scenario j and a_i is the marks allocated for availability of fuel i.

Table 15. Fuel availability of scenarios considered for 2030

Scenario	VLSFO %	HSFO %	MGO %	LNG %	Methanol %	Fuel Availability (A_j)
1	75%	0%	25%	0%	0%	9
2	70%	15%	15%	0%	0%	9
3	60%	30%	10%	0%	0%	9
4	55%	25%	10%	10%	0%	8.8
5	55%	25%	5%	10%	5%	8.5
6	60%	30%	5%	0%	5%	8.7
7	55%	0%	10%	35%	0%	8.3
8	50%	22%	5%	28%	0%	8.89

4.2.4 Investment cost on Infrastructure

CAPEX for construction of two nos. 5000MT HSFO tanks and construction of two nos of 12-inch pipelines were calculated as approximately USD 3 million. (Please refer Appendix 3 for cost break down). CAPEX for 15,000 m^3 FSRB for LNG is taken as USD 40 million. (Wärtsilä, 2018). CAPEX FOR 50,000 m3 FSRB for LNG is taken as USD 120 million. (Wärtsilä, 2018)

It is assumed introduction of methanol to JCT oil bank will not require additional infrastructure investment as it would be possible to share facilities used for MGO.

Summary of Investment cost on Infrastructure development for all scenarios are as follows:

Table 16. Summary of CAPEX requirement for scenarios considered for 2030

Scenario	VLSFO %	HSFO %	MGO %	LNG %	Methanol %	Investment cost on Infrastructure (USD million)
1	75%	0%	25%	0%	0%	0
2	70%	15%	15%	0%	0%	0
3	60%	30%	10%	0%	0%	3
4	55%	25%	10%	10%	0%	43
5	55%	25%	5%	10%	5%	43
6	60%	30%	5%	0%	5%	3
7	55%	0%	10%	35%	0%	120
8	50%	22%	5%	28%	0%	123

4.2.5 Technical Knowhow

Table 17. Marks allocation for Technical knowhow on each fuel for 2030

Technical Knowhow	Description	Marks out of 10	Fuel
Very High	Currently have very good knowledge and experience in handling, storage and testing of fuel.	10	HSFO MGO
High	Currently have reasonably good knowledge and experience in handling, storage and testing of fuel.	8	VLSFO
Moderate	Currently have limited knowledge and experience in handling, storage and testing of fuel.	6	
Poor	No practical experience in handling, storage and testing of fuel. But limited knowledge is available.	4	LNG
Very Poor	No practical experience in fuel. Very limited knowledge is available through literature.	1	Methanol

Overall marks for technical knowhow in each scenario (T_j) were calculated by summing the products of mark allocated for each fuel with the relevant share of fuel.

$$\textit{Overall Technical knowhow } (T_j) = \sum_{i=1}^{5}(t_i \text{ x } s_{ij}) \text{ , } \quad j = 1,2,3,\ldots, 8$$

s_{ij} is the share(%) of fuel i for the scenario j and t_i is the marks allocated for technical knowhow for fuel i.

Table 18. Technical knowhow of scenarios considered for 2030

Scenario	VLSFO %	HSFO %	MGO %	LNG %	Methanol %	Overall Technical Knowhow (T_j)
1	75%	0%	25%	0%	0%	8.5
2	70%	15%	15%	0%	0%	8.6
3	60%	30%	10%	0%	0%	8.8
4	55%	25%	10%	10%	0%	8.3
5	55%	25%	5%	10%	5%	7.85
6	60%	30%	5%	0%	5%	8.35
7	55%	0%	10%	35%	0%	6.8
8	50%	22%	5%	28%	0%	7.82

4.2.6 Throughput Capacity

Throughput capacity of JCT oil bank under each scenario as discussed in section 4.1 are as follows.

Table 19. Summary of throughput capacity under the scenarios considered for 2030

Scenario	VLSFO %	HSFO %	MGO %	LNG %	Methanol %	Throughput capacity (MT/year)
1	75%	0%	25%	0%	0%	510,000
2	70%	15%	15%	0%	0%	600,000
3	60%	30%	10%	0%	0%	840,000
4	55%	25%	10%	10%	0%	933,330
5	55%	25%	5%	10%	5%	933,330
6	60%	30%	5%	0%	5%	840,000
7	55%	0%	10%	35%	0%	834,545
8	50%	22%	5%	28%	0%	1,164,545

4.2.7 Increase in Operational Complexity

Increase in operational complexity relative to the present is taken as a criteria to analyze the different scenarios. Rational behind the allocated values as identified by the author for increase in operational complexity are tabulated below.

Table 20. Definition of operational complexity under each scenario

Scenario	Definition of Increase in Operational Complexity
1	This is the base line scenario
2	This scenario is for re-introduction of HSFO with additional operational procedures such as pipeline flushing and downgrading of trans mix products. Increase in operational complexity is taken as 25% relative to present condition.
3	This scenario also includes re-introduction of HSFO but with investment for two dedicated pipelines and new tanks resulting in low increase in operational complexity of 5%.
4	Introduction of 10% LNG is assumed to increase the operational complexity by 75%. With another 5% for re-intro of HSFO (after improvement in relevant infrastructure facilities), the total is 80%.
5	Increase in operational complexity due to introduction of Methanol using existing facilities available for MGO is taken as 15% while the presence of LNG 75%, HSFO 5% with relevant improvements in infrastructure. Hence, total is 95%.
6	Increase in operational complexity due to introduction of Methanol using existing facilities available for MGO is taken as 15% while the presence of HSFO 5% with relevant improvements in infrastructure. Hence, total is 20%.
7	This scenario does not consider investment on HSFO but for LNG with higher share of 35%. Introduction of LNG in higher capacity is assumed to increase the operational complexity by 90%, which includes stricter safety procedures.
8	This scenario includes re-introduction of HSFO with relevant infrastructure (5%) and introduction of LNG in higher capacity (90%). Hence total increase in operational complexity is taken as 95%.

Summary of the increase of operational complexity of each scenario are presented below.

Table 21. Increase of operational complexity for scenarios considered for 2030

Scenario	VLSFO %	HSFO %	MGO %	LNG %	Methanol %	Increase in Operational Complexity
1	75%	0%	25%	0%	0%	0%
2	70%	15%	15%	0%	0%	25%
3	60%	30%	10%	0%	0%	5%
4	55%	25%	10%	10%	0%	80%
5	55%	25%	5%	10%	5%	95%
6	60%	30%	5%	0%	5%	20%
7	55%	0%	10%	35%	0%	90%
8	50%	22%	5%	28%	0%	95%

4.3 Relative importance of Criteria/Attributes considered

Weights for the seven criteria were assigned by the author based on their importance as follows:

- Infrastructure development requirement : 0.15
- Increase in operational complexity : 0.1
- Technical Knowhow : 0.1
- Fuel Availability : 0.15
- Future Fuel Mix : 0.2
- Contribution to GHG emission per unit : 0.15
- Throughput Capacity : 0.15

Highest weight of 0.2 was assigned to 'Future fuel mix' as it is the main factor which determines the success of the scenario. Lowest weight of 0.1 were assigned to 'Increase in operational complexity' and 'Technical knowhow'. Technical knowhow can be imported if it is required and also developed. Hence, even though it may incur additional cost it will have a relatively lesser impact on implementation. Operational complexity affects the effort and cost, which can be managed internally and hence, it is also considered to have relatively lesser impact on implementation.

Sri Lanka being a developing country, it is expected that finding necessary funds for development could be somewhat challenging. Hence, infrastructure development requirement was assigned a moderate weight of 0.15. Fuel availability is also a moderate challenge unless fuel is available locally and hence assigned 0.15. GHG emission is also important considering the expected future regulations and responsibility to reduce it to minimize global warming while throughput capacity of proposed development also important to profitability. Hence, both the criteria were assigned a relatively moderate weight of 0.15.

4.4 TOPSIS Analysis

Technique for order preference by similarity to ideal solution (TOPSIS) is the selected MCDA technique for this study. The TOPSIS involves simple and straightforward methodology to select the most appropriate option out of many alternatives based on the considered attributes. It is intended to select the alternative that is closest to the best possible solution and the farthest to the worst possible solution simultaneously. According to Behzadian, Otaghsara, Yazdani & Ignatius (2012) TOPSIS is used in wide range of real-world applications including supply chain management, Design Engineering, Marketing Management, Health Safety and Environment Management, Human Resources Management, Energy Management, etc. Chen and Hwang, (1992); Yoon & Hwang (1995) as cited in Behzadian et al (2012) indicates, "TOPSIS makes full use of attribute information, provides a cardinal ranking of alternatives, and does not require attribute preferences to be independent".

TOPSIS method commences by normalizing of the initial decision matrix that consists of all alternatives and relevant attribute values. Step 2 is to generate the weighted normalized decision matrix. Step 3 involves identification of the positive and negative ideal solutions. Calculation of the separation measures for each alternative is done in Step4. The final step is to compute the relative closeness coefficients or the Similarities to Positive-Ideal Solutions.

4.4.1 TOPSIS analysis to select the most appropriate scenario for bunkering in 2030

Given below is the step-by-step explanation of TOPSIS analysis conducted to select the most appropriate scenario for bunkering in 2030.

Table 22. Initial Decision Matrix for TOPSIS Analysis for selecting the most appropriate scenario for bunkering in 2030.

Scenario	Infrastructure development requirement	Increase in operational complexity	Technical Knowhow	Fuel Availability	Dissimilarity with Future Fuel Mix	Contribution to GHG emission per unit (kg/MT)	Throughput Capacity (MT)
1	0	0%	8.5	9	48%	3,766.5	510,000
2	0	25%	8.6	9	30%	3,741.3	600,000
3	3	5%	8.8	9	13%	3,720.6	840,000
4	43	80%	8.3	8.8	14%	3,740.4	933,330
5	43	95%	7.85	8.5	13%	3,638.7	933,330
6	3	20%	8.35	8.7	13%	3,618.9	840,000
7	120	90%	6.8	8.3	47%	3,803.4	834,545
8	123	95%	7.82	8.89	27%	3,952.3	1,164,545

The first step of TOPSIS is to generate the normalized ratings to transform various attribute dimensions into the non-dimensional attribute.

The vector normalization technique is used for computing the element (r_{ij}) of the normalized decision matrix, which is given as; $r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$, i= 1,2,…,m; j= 1,2,….,n.

x_{ij} is the value of alternative i with respect to attribute j. (m=8, n=7)

Table 23. Normalized decision matrix

Scenario	Infrastructure development requirement	Increase in operational complexity	Technical Knowhow	Fuel Availability	Dissimilarity with Future Fuel Mix	Contribution to GHG emission per unit	Throughput Capacity
1	0.000	0.0000	0.369	0.363	0.5751	0.3552	0.2113
2	0.000	0.1364	0.373	0.363	0.3657	0.3528	0.2486
3	0.016	0.0273	0.382	0.363	0.1561	0.3509	0.3480
4	0.236	0.4364	0.360	0.354	0.1652	0.3527	0.3867
5	0.236	0.5183	0.341	0.342	0.1607	0.3432	0.3867
6	0.016	0.1091	0.362	0.350	0.1513	0.3413	0.3480
7	0.658	0.4910	0.295	0.334	0.5713	0.3587	0.3457
8	0.675	0.5183	0.339	0.358	0.3299	0.3727	0.4825

The weighted normalized decision matrix was calculated by multiplying each row of the normalized decision matrix with its associated attribute weight.

Table 24. Weighted normalized decision matrix

Scenario	Infrastructure development requirement	Increase in operational complexity	Technical Knowhow	Fuel Availability	Dissimilarity with Future Fuel Mix	Contribution to GHG emission per unit	Throughput Capacity
1	0.000	0.0000	0.037	0.073	0.0863	0.0533	0.0317
2	0.000	0.0136	0.037	0.073	0.0549	0.0529	0.0373
3	0.002	0.0027	0.038	0.073	0.0234	0.0526	0.0522
4	0.035	0.0436	0.036	0.071	0.0248	0.0529	0.0580
5	0.035	0.0518	0.034	0.068	0.0241	0.0515	0.0580
6	0.002	0.0109	0.036	0.070	0.0227	0.0512	0.0522
7	0.099	0.0491	0.030	0.067	0.0857	0.0538	0.0519
8	0.101	0.0518	0.034	0.072	0.0495	0.0559	0.0724

Next step is to identify Positive-Ideal and Negative-Ideal Solutions. Positive-ideal solution: A^* and the negative-ideal solution: A^- can be defined in terms of the weighted normalized values as follows:

$A^* = \{v_1^*, v_2^*, \ldots, v_j^*, \ldots, v_n^*\}$, where $v_j^* = \{ max_i v_{ij}, j \in j_1 ; \quad min_i v_{ij},\ j \in j_2 \}$

$A^- = \{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\}$, where $v_j^- = \{ min_i v_{ij}, j \in j_1 ; \quad max_i v_{ij},\ j \in j_2 \}$

j_1 is the set of benefit attributes and j_2 is the set of cost attributes.

Benefit attributes (j_1) includes Technical knowhow, Fuel availability and Throughput capacity where highest values of each attribute in the weighted normalized matrix corresponds to the positive ideal solutions and the lowest values represents the negative ideal solutions.

Cost attributes (j_2) includes Infrastructure development requirement, Increase in operational complexity, Dissimilarity with future fuel mix and Contribution to GHG emission per unit where lowest values in the weighted normalized matrix provides the best desirable outcomes or the positive ideal solutions and highest value of each attribute represents negative ideal solutions.

Table 25. Calculated positive and negative ideal solutions

	Infrastructure development	Increase in operational complexity	Technical Knowhow	Fuel Availability	Dissimilarity with Future Fuel Mix	Contribution to GHG emission per unit	Throughput Capacity
Positive Ideal Solutions (A^*)	0.000	0.000	0.038	0.073	0.0227	0.0512	0.0724
Negative Ideal Solutions (A^-)	0.101	0.052	0.030	0.067	0.0863	0.0559	0.0317

Separation of each alternative from the positive-ideal solution and negative ideal solution for a scenario is given by the n-dimensional Euclidean distance.

Separation from positive ideal solution $S_i^* = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^*)^2}$ $i = 1, 2, \ldots, m$

Separation from negative ideal solution $S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2}$ $i = 1, 2, \ldots, m$

Similarities to Positive-Ideal Solutions (C_i^*) or relative closeness of A_i with respect to A^* is defined by:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad , 0 < C_i^* < 1 ; i = 1, 2, \ldots \ldots, m$$

Alternative A_i is closer to A^* than to A^- as C_i^* approaches 1. Hence, Similarity to Positive-Ideal Solution is highest when it is close to 1.

Accordingly, calculated Similarities to Positive-Ideal Solutions (C_i^*) are presented in the Table 24 below.

Table 26. Calculated Similarities to Positive-Ideal Solutions

Scenario	Separation distance of each alternative from the Positive-ideal solution (S_i^*)	Separation distance of each alternative from the Negative-ideal solution (S_i^-)	Similarities to Positive-Ideal Solutions (C_i^*)	Final Rank
1	0.07550	0.11410	0.6018	5
2	0.04955	0.11321	0.6956	3
3	0.02056	0.12901	**0.8625**	**1**
4	0.05811	0.09454	0.6193	4
5	0.06465	0.09450	0.5938	6
6	0.02327	0.12633	0.8444	2
7	0.12907	0.02062	0.1377	8
8	0.11698	0.05522	0.3207	7

Based on the TOPSIS analysis, the best alternative or option for development of bunkering business in Colombo by 2030 is provided by the Scenario 3. Accordingly, the best outcome can be achieved after development of dedicated infrastructure to re-introduce HSFO. This is also very much in line with the opinion of the bunker operators as per the feedback received for the *questionnaire survey* where the requirement of development in infrastructure has been highlighted as an immediate requirement. In fact, such development should have been done earlier to the IMO 2020, which could have prevented loss of business opportunity for HSFO. Results of TOPSIS analysis, which was based on relevant multiple criteria for development of bunkering, can be identified as rational and acceptable. However, more refined analysis including exact profit margins and further refined data could provide results that are more accurate.

The Scenario 6 gives the second best alternative. This also includes development of infrastructure for HSFO similar to scenario 3 but introduction of methanol in addition. It is notable that even the increase in operational complexity due to having extra fuel (Methanol) to share the facilities and lower marks for fuel availability and technical knowhow for methanol has only resulted in a slightly lower mark or similarity to positive-ideal solution than the Scenario 3. Considering the closeness of the results, the actual decision can be taken later on after evaluating more up to date conditions and profitability since additional infrastructure development for methanol is not required.

The third best alternative is Scenario 2 where re-introduction of HSFO is suggested with additional operational procedures utilizing the existing facilities. It is evident that, this option has to be implemented immediately until further infrastructure developments are carried out to facilitate HSFO. This would enable to achieve higher throughput compared to current situation represented in the scenario 1, which is ranking in no 5 position.

Scenarios with LNG has obtained lower rankings mainly due to expected low demand for LNG, high infrastructure development cost and increase in operational complexity, which includes stringent safety requirements. Among the scenarios with LNG, Scenario 4 with 10% LNG is in the highest level of ranking by taking the fourth position. Despite its rank, this option also should not be neglected in the event of exploitation of local natural gas reserves in the future, which would change the attributes such as fuel availability and also profitability subject to reasonable demand. Scenario 5 and scenario 8 which includes LNG in the fuel mix are in the ranks of six and seventh.

Scenario 7 which does not include development of further infrastructure for fuel oil but high investment on LNG ranks last with extremely low similarity to positive-ideal solution.

5. Summary and Conclusion

Port of Colombo is a fast growing container port in the world. Availability of quality bunker fuel at a competitive price is very important for a port to attract ships as well as to generate foreign income. However, it is evident that attention given to develop the bunkering infrastructure in Colombo has been very poor in the past resulting in great challenges to face with after the implementation of IMO 2020 regulation.

Many industry experts had predicted many technical challenges with respect to the new fuel VLSFO 0.5% m/m Sulphur, which is different to the conventional fuel oil with respect to its composition and production process. It was not possible to produce VLSFO in the local refinery due to its limitations in the processing units. Despite of few incidents of low viscosity, low density and occasional low flash point reported in the VLSFO, bunkering activities in Colombo had been smooth without any major issues with the imported stocks of VLSFO. However, bunker operators have avoided HSFO, as it is very difficult to handle it together with VLSFO due to lack of infrastructure facilities.

The results of TOPSIS study conducted to choose the best option for bunkering indicates that it is required to develop infrastructure to cater HSFO requirement, to reach the best fuel mix for 2030 in Colombo. The suggested development increases the total fuel oil handling capacity by around 40% with dedicated pipelines to conduct simultaneous operations and it is expected to increase the annual throughput handling at least by 40% with respect to the current maximum capacity of 600,000 MT/year. Accordingly, expected throughput capacity in 2030 is 840,000 MT/year. However, if it is possible to provide bunker fuel at a more competitive price, the potential to grow the bunkering business is much higher.

Development of the local refinery will immensely contribute to the growth of bunkering business in Colombo, as it would be possible to produce bunker fuel locally to sell at a more competitive price. However, lack of finance has so far prevented it happening. Possibility of involving in offshore bunkering will also significantly improve if the bunker fuel can be make available at a competitive price.

Projected fuel mix in 2050 indicates the requirement of having Ammonia and LNG in the fuel mix, which will require separate infrastructure facilities. Presence of high percentage of LNG in 2050 fuel mix is somewhat doubtful considering its lack of advantage with respect to lifecycle GHG emission. TOPSIS analysis conducted for 2030 also indicates extremely low results for scenarios with LNG. However, situation could change after 2030 with improvements in technology to minimize methane slip and leakages throughout the supply chain. It will be prudent to carefully analyze the trends later on and plan accordingly. With respect to LNG or any other new fuel it would be required to explore the possibility of having long-term contracts with shipping lines to minimize the risk associated with the high investment costs. Alternatively, it is also possible to seek the opportunity to invite prospective shipping lines to form a joint venture on such investments.

Having located in the middle of East-West main shipping route, the option of bunkering in Colombo provides a good opportunity to reduce the energy consumption of ships by carrying lower quantity of fuel onboard resulting in reduction of GHG emission. This is also a good alternative to slow steaming. If the available bunker fuel options are less carbon intensive the overall outcome would be much better.

6. List of References

ABS. (2020). Practical considerations for the transition to compliant fuel 2020. Retrieved from https://www.standard-club.com/media/3229391/abs_transition-to-compliant-fuel.pdf

Alfa Laval (2018). The Alfa Laval Adaptive Fuel Line Blue Book, Technical reference booklet – 2018 Edition. Retrieved from https://www.alfalaval.com/globalassets/documents/industries/marine-and-transportation/marine/refuel/ Bluebook__en.pdf

Alfa Laval (2019). Fuel and operational considerations for 2020, Fuel oil system: 1.5 KBSD single line Fuel strategy: VLSFO. Retrieved from https://www.alfalaval.com/globalassets/documents/service/boiler-2020/technical-paper-1.5.pdf

Argyros, D., Raucci, C., Sabio, N., Smith, T. (2014). Global Marine Fuel Trends 2030. Lloyd's Register and University College London, London, UK. Retrieved from http://www.lrs.or.jp/news/pdf/GMFT2030_1p_tcm155-249392.pdf

Balcombea, P., Brierley, J., Lewis, C., Skatvedt, L., Speirsa, J., Hawkes, A., & Staffell,I. (2019). How to decarbonise international shipping: Options for fuels,technologies and policies. *Energy Conversion and Management*, 72-88. Retrieved from https://www.researchgate.net/publication/330308528_How_to_decarbonise_international_shipping_Options_for_fuels_technologies_and_policies

Baresic, D., Smith T., Raucci, K., Rehmatulla, C., Narula, N. & Rojon, I. 2018, 'LNG as a marine fuel in the EU: Market, bunkering infrastructure investments and risks in the context of GHG reductions', UMAS, London. Retrived from https://www.transportenvironment.org/sites/te/files/2018_06_LNG_marine_fuel_EU_UMAS_study.pdf

Barsamian, A. (2019). Everything you want to know about IMO 2020 but are afraid to ask. Hydrocarbon Processing, 98(7), 21–22. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=a9h&AN=137618587&site=eds-live&scope=site

Behzadian, M., Otaghsara, K., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, 39(17), 13051–13069. https://doi.org/10.1016/j.eswa.2012.05.056

Bockmann, M.W. (2019). Scrubber payback forecast within a year as fuel oil spreads stay wide. Retreived from https://lloydslist.maritimeintelligence.informa.com/LL1130234/Scrubber-payback-forecast-within-a-year-as-fuel-oil-spreads-stay-wide?vid=Maritime&processId=8edfac9e-be9f-45e7-9277-ffbd66377eec

Campara, L., Hasanspahić, N. & Vujicic, S. (2018). Overview of MARPOL ANNEX VI regulations for prevention of air pollution from marine diesel engines. Retrieved from https://www.researchgate.net/publication/329383051_Overview_of_MARPOL_ANNEX_VI_regulations_for_prevention_of_air_pollution_from_marine_diesel_engines

CIMAC. (2019). CIMAC Guideline - Marine fuel handling in connection to stability and compatibility. Retrieved from https://www.cimac.com/cms/upload/Publication_Press/WG_Publications/CIMAC_WG07_Guideline_Stability_and_Compatibility_Nov_2019.pdf

Clarksons Research. (2020a). Shipping Intelligence Weekly, Issue No. 1,406. Retrieved from https://sin.clarksons.net/Download/Downloadfile?DownloadToken=2acf6da1-61b0-4a31-a04b-7f3472ec1d3b&friendlyFileName=SIW%20Issue%201406%2017_01_2020.pdf

Clarksons Research. (2020b). Container Intelligence Quarterly, Third Quarter 2020. Retrieved from https://sin.clarksons.net/Download/Downloadfile?DownloadToken=7fa44614-a97c-4ba8-bde0-9673f64d1356&friendlyFileName=CIQ%202020%20Qtr%2003.pdf

Corbett, J.J., Winebrake, J.J., Carr, E.W., Jalkanen, J.P., Johansson,L., Prank, M., Sofiev, M., (2016). Health Impacts Associated with Delay of MARPOL Global Sulphur Standards. Retrieved from http://www.imo.org/en/MediaCentre/HotTopics/Documents/Finland%20study%20on%20 health%20benefits.pdf

CPC. (2020). Refinery. Retrieved from http://ceypetco.gov.lk/refinery.

DNV GL. (2019). Maritime forecast to 2050, Energy Transition Outlook 2019. Retrieved from https://eto.dnvgl.com/2019/download

Dollar Times. (2020). Inflation Calculator: The Changing Value of a Dollar. Retrieved from https://www.dollartimes.com/inflation/?

EMSA. (2018). Guidance on LNG Bunkering to Port Authorities & Administrations. Retrieved from https://www.parismou.org/sites/default/files/EMSA%20Guidance%20on%20LNG%20Bunkering.pdf

Engineering toolbox (2020). Fuels - Higher and Lower Calorific Values. Retrieved from https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

EPA (2019). Sulfur Dioxide (SO2) Pollution. Retrieved from https://www.epa.gov/so2-pollution/sulfur-dioxide-basics#effects

Gilbert, P., Walsh, C., Traut, M., Kesieme, U., Pazouki, K., Murphy, A. (2018). Assessment of full life-cycle air emissions of alternative shipping fuels. *Journal of Cleaner Production* 172, 855-866. Retrieved from https://www.sciencedirect.com/science/article/pii/S0959652617324721

Hansson, J., Brynolf, S., Fridell, E., & Lehtveer, M. (2020). The Potential Role of Ammonia as Marine Fuel—Based on Energy Systems Modeling and Multi-Criteria Decision Analysis. *Sustainability*, 12(3265), 3265. https://doi.org/10.3390/su12083265

Hansson, J., Månsson, S., Brynolf, S., & Grahn, M. (2019). Alternative marine fuels: Prospects based on multi-criteria decision analysis involving Swedish stakeholders. *Biomass and Bioenergy*, 126, 159–173. https://doi.org/10.1016/j.biombioe.2019.05.0080

Fernando, R. (2017, November 27),Developing the Sri Lankan Maritime Industry, Daily FT-E paper, Retrieved from http://www.ft.lk/opinion/Developing-the-Sri-Lankan-maritime-industry/14-644105

ICS (2019). Guidance to Shipping Companies and Crews on Preparing for Compliance with the 2020 'Global Sulphur Cap'for Ships' Fuel Oil in Accordance with MARPOL Annex VI. Retrieved from http://www.ics-shipping.org/docs/default-source/resources/ics-guidance-on-implementation-of-2020-global-sulphur-cap---january-2019.pdf?sfvrsn=20

IMO (2016a). Study on effects of the entry into force of the global 0.5% fuel oil Sulphur content limit on human health. MEPC 70/INF.34. Retrieved from https://docs.imo.org/Shared/Download.aspx?did=99022

IMO (2016b). IMO sets 2020 date for ships to comply with low sulphur fuel oil requirement. Retrieved from http://www.imo.org/en/MediaCentre/PressBriefings/Pages/MEPC-70-2020sulphur.aspx

IMO (2019). 2019 Guidelines for consistent implementation of the 0.50% sulphur limit under MARPOL Annex VI. Resolution MEPC.320(74). Retrieved from www.imo.org/en/OurWork/Environment/PollutionPrevention/Documents/Resolution%20MEPC.320%2874%29.pdf

IMO (2020). Fourth IMO GHG Study 2020 – Final report. Retrieved from https://docs.imo.org/Search.aspx?keywords=GHG%20study

Integer8 fuel. (2019). Buying fuel on calorific value as means to achieve savings. Retrieved from https://integr8fuels.com/wp-content/uploads/2019/12/Integr8-Research-2019-12-Calorific-value-analysis.pdf

IRENA [International Renewable Energy Agency], (2019). Navigating the way to a renewable future: solutions to decarbonise shipping. Retrived from https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Renewable_Shipping_Sep_2019.pdf

ISO (2019). ISO/PAS 23263:2019 Petroleum products - Fuels (class F) Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0.50 % sulphur in 2020. Retrieved from https://www.iso.org/standard/75113.html

JIG (2019). Joint industry guidance on potential safety and operational issues related to the supply and use of 0.50% maximum sulphur fuels. Retrieved from http://www.imo.org/en/MediaCentre/HotTopics/Documents/Joint_Industry_Guidance.pdf

Kim, A.R., & Seo, Y.J. (2019). The reduction of SOx emissions in the shipping industry: The case of Korean companies. *Marine Policy*, 100, 98–106. https://doi.org/10.1016/j.marpol.2018.11.024

Lankan exporters need to take advantage of connectivity provided by shipping lines. (2017, July 12), Dailymirror. Retrieved from http://www.dailymirror.lk/print/businessopinion/Lankan-exporters-need-to-take-advantage-of-connectivity-provided-by-shipping-lines/306-132652

Matches. (2014). Tank Cost Estimate. Retrieved from https://www.matche.com/equipcost/Tank.html

One Hundred Ports 2019 (2019). Retrieved from https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2019

Petak, K., Vidas, H., Manik,J., Palagummi, S., Ciatto, A., & Griffith, A. (2017). U.S. oil and gas infrastructure investment through 2035. Retrieved from https://www.api.org/news-policy-and-issues/energy-infrastructure/oil-gas-infrastructure-study-2017

Shell. (2019). Preparing for the disruptions that lie ahead. Retrieved from https://www.shell.com/business-customers/catalysts-technologies/resources-library/preparing-for-the-disruptions-that-lie-ahead.html

SLPA. (2020a). Colombo port – location. Retrieved from https://www.slpa.lk/port-colombo/location

SLPA, (2020b). Colombo port. Retrieved from https://www.slpa.lk/port-colombo/about-colombo

SLPA. (2016). Sri Lanka Ports Authority Annual Report 2016. Retrieved from https://www.parliament.lk/uploads/documents/paperspresented/annual-report-srilanka-ports-authority-2016.pdf

SLPA. (2017). Sri Lanka Ports Authority Annual Report 2017. Retrieved from https://www.parliament.lk/uploads/documents/paperspresented/annual-report-srilanka-ports-authority-2017.pdf

SLPA. (2018). Sri Lanka Ports Authority Annual Report 2018. Retrieved from https://www.parliament.lk/uploads/documents/paperspresented/annual-report-srilanka-ports-authority-2018.pdf

Speirs, J., Balcombe, P., Blomerus, P., Stettler, M., Brandon, N., & Hawkes, A. (2019). Can Natural gas reduce emissions from transport? Heavy goods vehicles and shipping. Retreived from https://www.sustainablegasinstitute.org/wp-content/uploads/2019/02/SGI-can-natural-gas-reduce-emissions-from-transport-WP4.pdf?noredirect=1

Wärtsilä. (2018). Developer's guide to small-scale LNG terminals. Retrieved from https://www.wartsila.com/docs/default-source/power-plants-documents/downloads/brochures/developers-guide-to-small-scale-lng-terminal.pdf

Appendix 1: Questionnaire for Bunker Operators

Questionnaire for Bunker Operators	Please indicate in this column if you do not wish to answer
1. How many years of experience does your Company have in ship bunkering? ☐	
2. How many years have you supplied ship bunker fuel at Colombo Port? ☐	
3. What type of fuel do you supply to vessels at Colombo Port? ➢ VLSFO (0.5% m/m Sulphur) ☐ ➢ HSFO (3.5% m/m Sulphur) ☐ ➢ MGO ☐ ➢ Other(Please specify) ☐	
4. What are the resources available at your company for the use of bunkering activities ? ☐	
5. What type of ships do you supply bunker fuel to? ➢ Container vessels ☐ ➢ Bulk Carriers ☐ ➢ General Cargo ☐ ➢ Tankers ☐ ➢ Passenger vessels ☐ **What percentage of above vessels are less than15 years in age**? ☐	
6. What average quantities do you supply per month in Colombo Port after implementation of IMO 2020 Sulphur regulation? ➢ VLSFO (0.5% m/m Sulphur) ☐ MT ➢ HSFO (3.5% m/m Sulphur) ☐ MT ➢ MGO ☐ MT ➢ Other(Please specify) ☐	

7. **What average quantities did you supply per month in Colombo Port before implementation of IMO 2020 Sulphur regulation?**
   - VLSFO (0.5% m/m Sulphur) ☐ MT
   - HSFO (3.5% m/m Sulphur) ☐ MT
   - MGO ☐ MT
   - Other(Please specify) ☐

8. **Have you received any complaints mentioned below related to quality of VLSFO (0.5% m/m Sulphur) from customers after implementation of IMO 2020 Sulphur regulation?**
   - Stability of Fuel Oil ☐ No of complaints ☐
   - Compatibility of Fuel Oil ☐ No of complaints ☐
   - Issue with Viscosity ☐ No of complaints ☐
   - Contamination ☐ No of complaints ☐
   - Other (Please provide information including number of complaints)

9. **What issues did you face after implementation of IMO 2020 Sulphur regulation?**

10. How did you overcome the above-mentioned issues and do you have any proposals to overcome related issues that needs to be addressed by other authorities?	
11. What barriers do you see in general to develop bunkering business at Colombo?	
12. In your opinion, what needs to be done to develop the bunkering business at Colombo?	
13. Are you aware of the IMO's strategy on reduction of GHG emission from international shipping? Yes ☐ No ☐	
14. Are you aware of the following fuel proposed to fuel ships in future? ➢ LNG Yes ☐ No ☐ ➢ Methanol Yes ☐ No ☐ ➢ Hydrogen Yes ☐ No ☐ ➢ Ammonia Yes ☐ No ☐ ➢ Biofuel Yes ☐ No ☐	

15. In your opinion, what are the advantages/disadvantages of these alternative fuels? Which alternative fuel infrastructure do you see as promising to invest in for the future and why? ☐	
16. Does your company or a partner company have any experience in supply of Liquefied Natural Gas (LNG) as a bunker fuel? Yes ☐ No ☐	
17. Do you think there will be a good market for LNG as a bunker fuel at Colombo Port in future? Yes ☐ No ☐ No Idea ☐	
18. Please provide any other comment or feedback related to ship bunkering that you think as important for this study. ☐	

Appendix 2: Summary of Findings of Questionnaire Survey

Question	Respondent1	Respondent2	Resporent3
1. How many years of experience does your Company have in ship bunkering?	13	12	30
2. How many years have you supplied ship bunker fuel at Colombo Port?	13	12	30
3. What type of fuel do you supply to vessels at Colombo Port?	VLSFO MGO LSMGO	VLSFO MGO	VLSFO MGO Inter mediate blended fuel oil
4. What are the resources available at your company for the use of bunkering activities ?	Bunker barges	Bunker barges	Own bunker barges Expertise and experienced staff Long term contracts with suppliers
5. What type of ships do you supply bunker fuel to? What percentage of above vessels are less than15 years in age?	Container Bulk General Cargo Tankers Passenger 50%	Container Bulk General Cargo Tankers Passenger	Container Bulk General Cargo Tankers Passenger
6. What average quantities do you supply per month in Colombo Port after implementation of IMO 2020 Sulphur regulation?	VLSFO : 12000 MT HSFO: Nil MGO : 3500 MT	VLSFO : 10000 MT HSFO: Nil MGO : 3000 MT	VLSFO : 15000 MT HSFO: Nil MGO : 2000 MT
7. What average quantities did you supply per month in Colombo Port before implementation of IMO 2020 Sulphur regulation?	VLSFO : Nil HSFO: 15000 MT MGO : 3000 MT	VLSFO : Nil HSFO: 10000 MT MGO : 2500 MT	VLSFO : Nil HSFO: 18000 MT MGO : 1500 MT

Question	Respondent1	Respondent2	Responent3
8. Have you received any complaints mentioned below related to quality of VLSFO (0.5% m/m Sulphur) from customers after implementation of IMO 2020 Sulphur regulation?	Issue with Viscosity -6 complaints Occasionally we also receive flash point issues	Issue with Viscosity -4 complaints	Density - few
9. What issues did you face after implementation of IMO 2020 Sulphur regulation	No issues critical as such , however tank cleaning was a issue with remaining resides However as more VLSFO cargo has turned now that issue is resolved	No major issues except for limited facilities and tank cleaning	Nothing significant. Only issue is in Colombo storage facility is very limited
10. How did you overcome the above-mentioned issues and do you have any proposals to overcome related issues that needs to be addressed by other authorities?	Engaging cleaning crew + cleaning lines with LSMGO	Additional flushing and cleaning.	Sufficient tanks are to be constructed.
11. What barriers do you see in general to develop bunkering business at Colombo?	Sri Lanka is not an oil nation, So Is a solo importer for all fuels and the refinery is not active So regionally vessels only come for top ups on extreme necessity	Poor infrastructure	Mostly the Red Tapes by the Govt Athorities.
12. In your opinion, what needs to be done to develop the bunkering business at Colombo?	Should have a productive refinery	Facilities for storage and pipelines are required to be added	1.Storage Facility to be increased and the storage charges to be revived. 2.Dedicated and prioritized discharging berth in the port should be made available. 3.Custom regulations to be revived to facilitate the industry.
13. Are you aware of the IMO's strategy on reduction of GHG emission from international shipping?	Yes	Yes	Yes

Question	Respondent1	Respondent2	Responent3
14. Are you aware of the following fuel proposed to fuel ships in future?	LNG - Yes Methanol - No Hydrogen - No Ammonia- No Biofuel -Yes	LNG - Yes Methanol - No Hydrogen - Yes Ammonia- No Biofuel -Yes	LNG - Yes Methanol - No Hydrogen - Yes Ammonia- No Biofuel -No
15. In your opinion, what are the advantages/ disadvantages of these alternative fuels? Which alternative fuel infrastructure do you see as promising to invest in for the future and why	Less emission higher burning efficiency and more sailing productivity Also clean to handle less hazardous in terms of oil spills	Good for Environment	-
16. Does your company or a partner company have any experience in supply of Liquefied Natural Gas (LNG) as a bunker fuel?	No	No	No
17. Do you think there will be a good market for LNG as a bunker fuel at Colombo Port in future?	No	No	Yes
18. Please provide any other comment or feedback related to ship bunkering that you think as important for this study	Regulatory frame works , IMO's guidelines , WCO policies		1.Latest and practical Oil spill prevention and spill handling methodologies to be introduced to the industry. 2.Standard laboratory facility should be made available to test ISO 8217-2020.

Appendix 3: Infrastructure Development Cost Estimate

<u>**Cost estimate for two nos. of 5,500 m^3 tanks**</u>

- Cost of 5,500m^3 (1,452,946 US gallon) API cone roof field fabricated carbon steel tank in 2014 USD = 416,300 USD (Matches, 2014)
- Adjusted for inflation, $416,300.00 in 2014 is equal to $459,037.70 in 2020 (Dollar Times, 2020)
- Hence approximate cost for 5,500m^3 tank = 460,000 USD
- Cost of two 5,500 m^3 tanks = 460,000 USD x 02 = 920,000 USD
- Installation of radar tank gauging system for two tanks = 54,000 USD (Based on previous project cost at JCT Ltd.)
- Cost of expansion of fire foam system and cooling water spray system for new two tanks = 75,000 USD (Based on previous project cost at JCT Ltd.)
- Approximate cost for site clearing and civil engineering work = 150,000 USD
- **Total cost for two 5,500 m^3 tanks complete with tank gauging and firefighting facilities = 920,000+54,000+75,000+150,000 = <u>1,199,000 USD</u>**

<u>Note:</u> The JCT oil bank is currently equipped with 04 nos. of pumps for fuel oil and 02 nos. of pumps for MGO. Hence, it is assumed that additional pumps are not required. Since the proposed new tanks are smaller than the largest tank in the facility, the current firewater storage capacity should be sufficient and bund walls to be joined to share the existing bund wall secondary containment capacity.

<u>**Cost Estimate for Two nos. of 12 inch Pipelines from JCT oil bank to SLPA South Jetty**</u>

- Approximate pipeline trace distance from JCT oil bank to SLPA South Jetty is 1.2 km (0.75 miles). The diameter of existing fuel oil transfer pipeline is 12 inch.
- Petak et al (2017) indicates the total construction cost rate for a 12-inch diameter oil pipeline in USA as USD 83,137 per inch-mile for the year 2016.
- Adjusted for inflation, $83,137.00 in 2016 is equal to $90,324.69 in 2020. (Dollar Times, 2020)
- Hence total construction cost for 1.2 km (0.75 miles) length of 12-inch diameter oil transfer pipeline= 0.75x12x90,325 = 812,925.00 USD
- **Total construction cost for 02 nos. of 1.2 km (0.75 miles) length, 12-inch oil transfer pipelines = 812,925.00 x 02 = <u>1,625,850.00 USD</u>**

Total cost for construction of 02 nos. of 5,500 m3 tanks and 02 nos. of 1.2 km length, 12-inch diameter oil transfer pipelines = 1,199,000 + 1,625,850.00 = <u>2,824,850.00 USD</u>

Appendix 4: Total SO_x Scrubber Fitted Ships in the World Fleet

Source: Clarkson Research Services Limited 2020.

	World Fleet, Total SOx Scrubber Fitted		World Fleet, Total SOx Scrubber Fitted		World Fleet, Total SOx Scrubber Fitted	
Date	**No**	**% (No)**	**GT million**	**% (GT)**	**DWT million**	**% (DWT)**
Jan-2015	98	0.1100	4.38	0.3700	2.20	0.1300
Feb-2015	122	0.1300	5.22	0.4400	2.53	0.1400
Mar-2015	130	0.1400	5.95	0.5000	3.24	0.1800
Apr-2015	142	0.1500	6.41	0.5400	3.46	0.2000
May-2015	157	0.1700	7.56	0.6300	3.74	0.2100
Jun-2015	170	0.1800	8.47	0.7100	4.04	0.2300
Jul-2015	177	0.1900	8.68	0.7200	4.26	0.2400
Aug-2015	179	0.1900	8.72	0.7200	4.29	0.2400
Sep-2015	182	0.2000	8.80	0.7300	4.39	0.2400
Oct-2015	188	0.2000	8.95	0.7400	4.50	0.2500
Nov-2015	194	0.2100	9.37	0.7700	4.66	0.2600
Dec-2015	**202**	**0.2200**	**9.67**	**0.7900**	**4.83**	**0.2700**
Jan-2016	208	0.2200	10.17	0.8300	4.87	0.2700
Feb-2016	222	0.2400	10.82	0.8800	5.11	0.2800
Mar-2016	227	0.2400	11.16	0.9100	5.18	0.2800
Apr-2016	239	0.2500	12.06	0.9800	5.43	0.3000
May-2016	250	0.2700	12.98	1.0500	5.56	0.3000
Jun-2016	259	0.2800	13.76	1.1100	5.67	0.3100
Jul-2016	265	0.2800	14.30	1.1500	5.90	0.3200
Aug-2016	266	0.2800	14.33	1.1500	5.93	0.3200
Sep-2016	271	0.2900	14.38	1.1500	5.98	0.3200
Oct-2016	274	0.2900	14.71	1.1700	6.01	0.3200
Nov-2016	281	0.3000	15.03	1.2000	6.11	0.3300
Dec-2016	**287**	**0.3000**	**15.24**	**1.2100**	**6.21**	**0.3300**
Jan-2017	294	0.3100	15.65	1.2400	6.32	0.3400
Feb-2017	299	0.3100	15.83	1.2500	6.45	0.3400
Mar-2017	302	0.3200	16.06	1.2600	6.50	0.3400
Apr-2017	306	0.3200	16.37	1.2800	6.59	0.3500
May-2017	315	0.3300	17.14	1.3400	6.79	0.3600
Jun-2017	320	0.3400	17.68	1.3700	6.89	0.3600
Jul-2017	321	0.3400	17.83	1.3800	7.19	0.3800
Aug-2017	325	0.3400	17.99	1.3900	7.27	0.3800
Sep-2017	330	0.3500	18.17	1.4000	7.52	0.3900
Oct-2017	333	0.3500	18.29	1.4100	7.59	0.3900
Nov-2017	338	0.3500	18.51	1.4200	7.70	0.4000
Dec-2017	**344**	**0.3600**	**19.03**	**1.4600**	**7.79**	**0.4000**

Date	World Fleet, Total SOx Scrubber Fitted		World Fleet, Total SOx Scrubber Fitted		World Fleet, Total SOx Scrubber Fitted	
	No	% (No)	GT million	% (GT)	DWT million	% (DWT)
Jan-2018	348	0.3600	19.37	1.4800	7.84	0.4100
Feb-2018	360	0.3700	20.06	1.5300	8.36	0.4300
Mar-2018	364	0.3800	20.22	1.5400	8.42	0.4300
Apr-2018	374	0.3900	21.16	1.6100	8.97	0.4600
May-2018	383	0.4000	21.71	1.6400	9.33	0.4800
Jun-2018	392	0.4100	22.27	1.6800	10.10	0.5200
Jul-2018	401	0.4200	22.64	1.7000	10.37	0.5300
Aug-2018	416	0.4300	23.61	1.7700	11.89	0.6100
Sep-2018	429	0.4400	24.11	1.8100	12.60	0.6400
Oct-2018	442	0.4600	24.84	1.8600	13.81	0.7000
Nov-2018	460	0.4700	26.23	1.9600	15.86	0.8000
Dec-2018	**478**	**0.4900**	**27.56**	**2.0500**	**17.58**	**0.8900**
Jan-2019	504	0.5200	29.52	2.2000	20.29	1.0200
Feb-2019	566	0.5800	34.31	2.5400	28.51	1.4300
Mar-2019	605	0.6200	37.26	2.7500	32.70	1.6400
Apr-2019	654	0.6700	40.53	2.9800	38.19	1.9000
May-2019	733	0.7500	46.70	3.4300	48.48	2.4100
Jun-2019	829	0.8500	53.62	3.9200	60.25	2.9900
Jul-2019	957	0.9800	64.41	4.6900	79.18	3.9100
Aug-2019	1,081	1.1000	74.75	5.4200	96.31	4.7400
Sep-2019	1,232	1.2600	87.02	6.3000	117.99	5.7900
Oct-2019	1,406	1.4300	100.61	7.2500	139.81	6.8300
Nov-2019	1,604	1.6300	116.96	8.4000	166.14	8.0900
Dec-2019	**1,811**	**1.8400**	**132.87**	**9.5200**	**192.11**	**9.3200**
Jan-2020	2,032	2.0600	149.74	10.7100	218.35	10.5800
Feb-2020	2,292	2.3200	170.45	12.1400	251.84	12.1400
Mar-2020	2,431	2.4600	181.14	12.8900	269.15	12.9700
Apr-2020	2,622	2.6500	195.36	13.8700	290.72	13.9700
May-2020	2,829	2.8600	212.38	15.0300	317.84	15.2300
Jun-2020	2,981	3.0100	224.49	15.8500	335.20	16.0200
Jul-2020	3,163	3.1900	237.94	16.7500	355.09	16.9100
Aug-2020	**3,295**	**3.3200**	**249.54**	**17.5500**	**372.47**	**17.7100**

Appendix 5: Total LNG Capable Fleet

Source: Clarkson Research Services Limited 2020.

Date	Total LNG Capable Fleet		Total LNG Capable Fleet		Total LNG Capable Fleet	
	No	% (No)	GT million	% (GT)	DWT million	% (DWT)
Jan-2015	243	0.2600	19.14	1.6200	15.26	0.8700
Feb-2015	251	0.2700	19.78	1.6700	15.79	0.9000
Mar-2015	255	0.2800	19.90	1.6700	15.89	0.9000
Apr-2015	256	0.2800	19.92	1.6700	15.89	0.9000
May-2015	259	0.2800	20.23	1.6900	16.16	0.9100
Jun-2015	261	0.2800	20.28	1.6900	16.19	0.9100
Jul-2015	267	0.2900	20.66	1.7200	16.50	0.9300
Aug-2015	272	0.2900	21.00	1.7400	16.79	0.9400
Sep-2015	275	0.3000	21.11	1.7400	16.88	0.9400
Oct-2015	278	0.3000	21.48	1.7700	17.18	0.9500
Nov-2015	282	0.3000	21.54	1.7600	17.24	0.9500
Dec-2015	**286**	**0.3100**	**21.79**	**1.7800**	**17.42**	**0.9600**
Jan-2016	291	0.3100	22.07	1.8000	17.56	0.9700
Feb-2016	297	0.3200	22.60	1.8400	17.97	0.9900
Mar-2016	298	0.3200	22.71	1.8400	18.07	0.9900
Apr-2016	303	0.3200	23.29	1.8800	18.42	1.0100
May-2016	304	0.3200	23.29	1.8800	18.42	1.0100
Jun-2016	306	0.3300	23.33	1.8800	18.44	1.0100
Jul-2016	310	0.3300	23.70	1.9000	18.71	1.0200
Aug-2016	312	0.3300	23.93	1.9200	18.91	1.0200
Sep-2016	314	0.3300	24.07	1.9200	19.02	1.0300
Oct-2016	320	0.3400	24.49	1.9500	19.32	1.0400
Nov-2016	326	0.3400	25.00	1.9900	19.72	1.0600
Dec-2016	**334**	**0.3500**	**25.45**	**2.0200**	**20.03**	**1.0700**
Jan-2017	339	0.3600	25.83	2.0500	20.34	1.0900
Feb-2017	347	0.3700	26.38	2.0800	20.74	1.1000
Mar-2017	350	0.3700	26.51	2.0800	20.84	1.1000
Apr-2017	358	0.3800	27.03	2.1100	21.27	1.1200
May-2017	364	0.3800	27.41	2.1400	21.48	1.1300
Jun-2017	367	0.3800	27.53	2.1400	21.59	1.1300
Jul-2017	371	0.3900	27.89	2.1600	21.89	1.1400
Aug-2017	375	0.3900	28.23	2.1800	22.15	1.1500
Sep-2017	378	0.4000	28.24	2.1800	22.16	1.1500
Oct-2017	380	0.4000	28.36	2.1800	22.27	1.1600
Nov-2017	385	0.4000	29.00	2.2300	22.80	1.1800
Dec-2017	**388**	**0.4000**	**29.17**	**2.2400**	**22.93**	**1.1900**

Date	Total LNG Capable Fleet		Total LNG Capable Fleet		Total LNG Capable Fleet	
	No	% (No)	GT million	% (GT)	DWT million	% (DWT)
Jan-2018	390	0.4100	29.43	2.2500	23.12	1.2000
Feb-2018	400	0.4200	30.49	2.3200	23.98	1.2300
Mar-2018	405	0.4200	30.89	2.3500	24.30	1.2500
Apr-2018	414	0.4300	31.91	2.4200	25.03	1.2900
May-2018	419	0.4300	32.41	2.4500	25.40	1.3000
Jun-2018	421	0.4400	32.59	2.4600	25.53	1.3100
Jul-2018	425	0.4400	33.07	2.4900	25.87	1.3200
Aug-2018	436	0.4500	33.79	2.5400	26.51	1.3500
Sep-2018	440	0.4500	34.29	2.5700	26.88	1.3700
Oct-2018	445	0.4600	34.56	2.5800	27.10	1.3700
Nov-2018	452	0.4700	35.07	2.6200	27.48	1.3900
Dec-2018	**460**	**0.4700**	**35.70**	**2.6600**	**28.02**	**1.4100**
Jan-2019	470	0.4800	36.42	2.7100	28.46	1.4400
Feb-2019	477	0.4900	37.10	2.7400	29.04	1.4600
Mar-2019	485	0.5000	37.74	2.7800	29.64	1.4800
Apr-2019	493	0.5100	38.16	2.8100	30.00	1.5000
May-2019	498	0.5100	38.50	2.8200	30.35	1.5100
Jun-2019	506	0.5200	39.16	2.8600	30.85	1.5300
Jul-2019	509	0.5200	39.39	2.8700	31.04	1.5300
Aug-2019	522	0.5300	40.40	2.9300	31.72	1.5600
Sep-2019	526	0.5400	40.76	2.9500	32.04	1.5700
Oct-2019	533	0.5400	41.40	2.9800	32.54	1.5900
Nov-2019	534	0.5400	41.46	2.9800	32.60	1.5900
Dec-2019	**538**	**0.5500**	**41.85**	**3.0000**	**32.91**	**1.6000**
Jan-2020	544	0.5500	42.22	3.0200	33.03	1.6000
Feb-2020	547	0.5500	42.36	3.0200	33.21	1.6000
Mar-2020	554	0.5600	42.97	3.0600	33.78	1.6300
Apr-2020	558	0.5600	43.14	3.0600	33.93	1.6300
May-2020	560	0.5700	43.39	3.0700	34.12	1.6300
Jun-2020	565	0.5700	43.96	3.1000	34.59	1.6500
Jul-2020	569	0.5700	44.31	3.1200	34.89	1.6600
Aug-2020	**574**	**0.5800**	**44.74**	**3.1500**	**35.31**	**1.6800**

Appendix 6: Total LNG Capable Orderbook

Source: Clarkson Research Services Limited 2020.

Year	Total LNG Capable Orderbook		Total LNG Capable Orderbook		Total LNG Capable Orderbook	
	No	% (No)	GT million	% (GT)	DWT million	% (DWT)
2005	51	0.8000	5.21	3.3200	4.17	1.8300
2006	63	0.8300	5.88	3.3000	4.71	1.8900
2007	63	0.6400	5.81	2.2700	4.76	1.2500
2008	59	0.4400	5.53	1.5100	4.56	0.8200
2009	57	0.4000	4.56	1.1400	3.76	0.6000
2010	45	0.3600	3.74	1.1000	3.07	0.5700
2011	40	0.3400	2.09	0.6600	1.62	0.3100
2012	81	0.8200	6.30	2.4300	4.83	1.2000
2013	120	1.5400	10.18	5.4600	7.89	2.8900
2014	159	1.9800	13.10	5.9400	10.09	3.1300
2015	220	2.9100	17.50	7.8200	13.40	4.0900
2016	233	3.3400	19.27	8.6300	14.17	4.4200
2017	212	3.7400	16.83	10.0200	12.28	5.3000
2018	229	4.2700	19.97	12.6400	15.32	6.9900
2019	283	5.5400	22.66	14.1000	17.99	7.9300
2020	364	8.5600	28.20	19.9500	24.04	12.3700

Appendix 7: LNG Fuel Capable Container ships By Size Range

Vessel Type	Fleet No.	% Total Fleet No.	Fleet m TEU	% Total Fleet m TEU	Orderbook No.	% Total Obk No.	Orderbook m TEU	% Total Obk m TEU
Sub-3,000 TEU	5	*0.2%*	0.01	*0.16%*	6	*2.9%*	0.01	*2.5%*
3,000-5,999 TEU	2	*0.2%*	0.01	*0.13%*				
6,000-7,999 TEU								
8,000-11,999 TEU								
12,000-14,999 TEU					13	*46.4%*	0.19	*48.3%*
15,000+ TEU					14	*26.9%*	0.28	*26.3%*
Total	**7**	***0.1%***	**0.01**	***0.06%***	**33**	***10.2%***	**0.48**	***22.3%***

Source: Clarksons Research.

Appendix 8: SOx Scrubber Equipped Container Ships (Fitted and Pending)

Source: Clarkson Research Services Limited 2020.

SOx Scrubber Equipped Boxship Fleet (Fitted And Pending) By Size Range - Numbers

Vessel Type	Fleet With Scrubbers No.*	% Total Fleet No.	Of which Fitted at Newbuilding	Of which Retro-fitted	Of which Retrofit Pending	Orderbook No.	% Total Obk No.
Sub-3,000 TEU	216	*7%*	76	113	27	47	*23%*
3,000-5,999 TEU	96	*9%*		76	20		
6,000-7,999 TEU	46	*17%*		44	2		
8,000-11,999 TEU	192	*31%*	4	125	63	18	*67%*
12,000-14,999 TEU	132	*52%*	9	76	47	10	*36%*
15,000+ TEU	110	*65%*	25	75	10	38	*73%*
Total	**792**	***15%***	**114**	**509**	**169**	**113**	***35%***

*Source: Clarksons Research. Figures will underestimate the total; data excludes some scrubber orders still to be linked/validated to individual vessels, and there may also be reporting lags. * 'Fleet with Scrubbers' includes delivered newbuilds, completed retrofits and pending retrofits. Contact Clarksons Research and/or visit World Fleet Register for the latest numbers.*

SOx Scrubber Equipped Boxship Fleet (Fitted And Pending) By Size Range - m TEU

Vessel Type	Fleet With Scrubbers m TEU*	% Total Fleet TEU	Of which Fitted at NB	Of which Retro-fitted	Of which Retrofit Pending	Orderbook m TEU	% Total Obk TEU
Sub-3,000 TEU	0.41	*10%*	0.14	0.22	0.05	0.09	*26%*
3,000-5,999 TEU	0.43	*9%*		0.34	0.09		
6,000-7,999 TEU	0.31	*17%*		0.30	0.01		
8,000-11,999 TEU	1.76	*30%*	0.04	1.16	0.55	0.20	*67%*
12,000-14,999 TEU	1.79	*52%*	0.13	1.03	0.63	0.14	*35%*
15,000+ TEU	2.11	*66%*	0.54	1.40	0.17	0.79	*74%*
Total	**6.80**	***29%***	**0.85**	**4.44**	**1.51**	**1.22**	***56%***

*Source: Clarksons Research. Figures will underestimate the total; data excludes some scrubber orders still to be linked/validated to individual vessels, and there may also be reporting lags. * 'Fleet with Scrubbers' includes delivered newbuilds, completed retrofits and pending retrofits. Contact Clarksons Research and/or visit World Fleet Register for the latest numbers.*

Appendix 9: Containership Fleet By Year Of Build

Year	Feeder 100-2,999 No.	Feeder ,000 TEU	Intermediate 3,000-5,999 No.	Intermediate ,000 TEU	Intermediate 6,000-7,999 No.	Intermediate ,000 TEU	Neo-Panamax 8,000-11,999 No.	Neo-Panamax ,000 TEU	Neo-Panamax 12,000-14,999 No.	Neo-Panamax ,000 TEU	Post-Panamax 15,000+ No.	Post-Panamax ,000 TEU	Total Fleet No.	Total Fleet ,000 TEU
<=1986	81	49.8	3	9.1									**84**	**58.9**
1987	8	11.6											**8**	**11.6**
1988	8	8.3											**8**	**8.3**
1989	13	14.9	1	4.8									**14**	**19.7**
1990	12	13.2	3	14.4									**15**	**27.7**
1991	27	17.4	3	9.0									**30**	**26.5**
1992	12	10.8	2	7.7									**14**	**18.4**
1993	32	29.2	10	33.9									**42**	**63.1**
1994	52	48.4											**52**	**48.4**
1995	68	59.1	4	19.1									**72**	**78.2**
1996	97	92.7	10	43.3	4	29.6							**111**	**165.6**
1997	134	160.4	10	40.5			2	19.3					**146**	**220.1**
1998	141	165.5	11	44.8	4	26.8	4	37.0					**160**	**274.0**
1999	83	104.1	16	82.3			4	38.5					**103**	**224.9**
2000	79	115.2	35	174.2	8	51.3	4	38.5					**126**	**379.2**
2001	86	145.2	43	202.7	19	124.6	1	9.6					**149**	**482.2**
2002	105	166.0	45	205.6	21	136.1	4	35.5					**175**	**543.3**
2003	96	155.5	38	169.6	19	125.7	6	49.2					**159**	**500.1**
2004	91	137.6	53	258.1	10	71.5	15	124.5					**169**	**591.8**
2005	148	219.1	74	343.9	11	76.7	33	290.4					**266**	**930.1**
2006	217	323.4	73	321.7	23	154.7	58	507.7			2	35.6	**373**	**1,343.2**
2007	241	341.7	103	450.8	28	183.9	33	293.8			5	89.1	**410**	**1,359.2**
2008	252	383.6	103	449.5	28	185.5	49	464.1	1	13.8	1	17.8	**434**	**1,514.4**
2009	124	190.7	97	419.9	21	139.9	30	279.2	5	67.9			**277**	**1,097.5**
2010	84	130.2	91	396.3	26	171.7	37	335.5	25	338.7			**263**	**1,372.4**
2011	69	94.9	37	172.5	15	102.0	43	395.7	35	464.9			**199**	**1,230.0**
2012	80	92.5	50	225.5	8	54.2	36	324.7	42	559.9	1	16.0	**217**	**1,272.9**
2013	50	74.1	61	259.7	14	93.2	50	440.7	22	291.9	12	208.9	**209**	**1,368.4**
2014	56	71.3	46	212.1	5	32.8	58	546.6	25	338.2	18	324.8	**208**	**1,525.8**
2015	67	99.6	21	91.5	3	20.5	75	704.5	19	270.3	26	474.4	**211**	**1,660.9**
2016	69	98.3	2	8.1			34	330.8	16	230.2	13	245.4	**134**	**912.8**
2017	79	126.5	6	23.8	1	6.9	27	285.3	20	284.7	23	447.4	**156**	**1,174.4**
2018	99	168.6	10	37.4			18	196.8	22	309.3	30	586.4	**179**	**1,298.4**
2019	104	160.9	7	24.8			2	23.6	18	247.3	30	606.7	**161**	**1,063.3**
2020	40	78.9	1	4.0			2	22.0	3	44.9	7	158.5	**53**	**308.2**
Total	**3,004**	**4,159.1**	**1,069**	**4,760.6**	**268**	**1,787.7**	**625**	**5,793.8**	**253**	**3,461.8**	**168**	**3,211.0**	**5,387**	**23,173.9**
Avg Age (years):		**14.6**		**12.9**		**13.3**		**9.1**		**6.1**		**3.7**		**12.8**

12-14,999 TEU 'Neo-Panamax' fleet includes some ships which are too large to transit the expanded locks of the Panama Canal based on current official dimension restrictions; 15,000+ TEU 'Post-Panamax' fleet includes some ships which are able to transit the expanded locks.

Source: Clarksons Research

Appendix 10: Worldwide Bunker Price Trends

US$/t	Rotterdam			Singapore			Fujairah			Houston		
Avg.	380cst	MGO	VLSFO	380cst	MGO	VLSFO	380cst	MGO	VLSFO	380cst	MGO	VLSFO
2000	138.4	252.9		158.7	258.0		155.3	269.9		136.0		
2001	117.4	217.8		133.1	214.7		129.7	250.5		112.8		
2002	133.7	209.9		148.9	209.6		145.9	227.6		134.0		
2003	152.9	256.1		172.0	246.1		166.3	270.1		160.2		
2004	155.3	352.5		180.3	341.8		176.7	364.1		167.3		
2005	234.0	506.8		261.9	485.9		256.6	506.5		248.3		
2006	293.0	573.6		313.2	574.0		310.9	618.8		303.0		
2007	345.1	627.6		372.8	634.2		373.7	670.3		351.8		
2008	471.9	918.4		505.6	913.6		509.4	1,019.2		496.8		
2009	353.8	528.9		371.9	529.2		372.8	595.4		360.7		
2010	450.2	682.7		464.1	668.9		468.2	716.5		449.3		
2011	617.9	944.5		646.9	940.9		652.9	1,022.1		625.7		
2012	639.6	955.3		664.1	958.3		668.5	1,037.5		646.6	1,053.0	
2013	594.8	903.8		615.9	927.3		616.8	1,001.9		602.7	997.3	
2014	532.1	816.6		559.7	856.7		561.8	960.4		545.5	935.1	
2015	264.1	479.6		291.6	498.2		292.0	692.3		271.0	546.4	
2016	213.1	383.4		232.8	401.6		233.2	491.3		209.3	430.0	
2017	305.2	473.6		328.7	493.0		324.1	565.9		302.3	510.6	
2018	399.9	614.2		432.2	641.1		429.8	714.7		400.5	648.7	
2019	349.1	567.7		403.1	596.8		379.1	706.8		383.0	617.2	
2020	225.7	370.2	331.8	251.6	400.8	387.7	235.3	509.7	394.4	246.6	405.9	356.8
Dec-17	345.7	545.4		373.5	560.3		361.7	613.2		350.6	578.1	
Jan-18	370.8	590.6		392.1	594.3		386.8	646.6		366.9	619.9	
Feb-18	355.8	561.4		375.0	584.6		374.4	666.9		352.3	598.9	
Mar-18	350.2	558.6		367.2	586.2		373.1	667.4		353.2	591.6	
Apr-18	374.5	607.5		398.8	634.5		397.5	675.0		366.9	623.1	
May-18	416.8	657.5		441.8	671.0		442.8	719.1		424.4	677.5	
Jun-18	422.3	636.5		448.1	664.4		449.9	728.5		422.8	674.0	
Jul-18	425.8	624.5		462.8	655.0		448.4	713.3		433.0	669.9	
Aug-18	422.2	629.6		459.7	669.8		458.5	720.8		422.5	673.7	
Sep-18	436.6	666.9		471.5	706.1		478.0	765.3		438.1	702.4	
Oct-18	466.4	689.5		504.8	737.4		511.6	790.5		458.8	730.6	
Nov-18	413.9	625.1		478.6	657.1		456.8	757.4		411.5	654.0	
Dec-18	343.6	522.5		385.6	532.3		379.8	725.8		356.3	568.8	
Jan-19	346.1	524.9		385.1	548.6		369.0	725.3		364.4	568.1	
Feb-19	388.3	558.9		423.1	595.6		406.0	733.5		406.9	607.5	
Mar-19	411.3	584.7		431.5	617.1		431.2	731.7		430.7	639.4	
Apr-19	423.9	596.9		436.3	625.6		437.3	740.8		429.4	653.8	
May-19	402.7	605.3		415.1	620.6		420.5	718.6		409.9	637.8	
Jun-19	366.0	549.9		390.5	579.5		386.0	689.4		363.6	589.3	
Jul-19	389.1	565.9		460.9	605.8		420.8	694.4		400.5	613.9	
Aug-19	311.2	545.7		393.1	586.0		370.7	676.8		329.9	589.7	
Sep-19	338.3	579.9	528.1	459.6	594.3	553.9	412.8	693.4	597.5	400.6	621.9	
Oct-19	287.0	564.6	510.4	360.8	580.4	540.4	326.8	679.4	566.7	373.6	611.5	520.1
Nov-19	258.4	559.8	503.2	341.6	582.2	549.3	279.5	684.5	574.1	330.3	622.9	582.6
Dec-19	267.5	576.3	538.0	340.1	626.0	626.3	288.6	713.8	631.7	356.8	645.0	601.4
Jan-20	296.1	553.0	536.6	366.2	663.6	663.4	307.8	742.9	687.2	351.1	622.0	590.5
Feb-20	293.8	481.2	451.7	315.0	513.3	503.0	304.9	635.9	507.8	355.3	536.9	487.9
Mar-20	205.8	339.1	284.9	215.6	344.4	327.4	237.6	510.0	341.2	227.4	392.8	328.7
Apr-20	158.5	263.9	210.7	185.4	262.4	250.2	169.9	410.1	250.4	164.4	288.4	227.9
May-20	164.3	253.0	215.3	184.5	269.9	257.3	162.6	352.0	255.5	161.7	264.8	226.2
Jun-20	236.1	331.1	284.4	243.0	351.2	316.0	229.2	407.1	316.7	219.6	335.4	285.0

Note: VLSFO prices basis range of industry sources, basis max. sulphur content of 0.5%. 380cst (HSFO) prices basis max. sulphur content of 3.5%.
Source: Clarksons Research

Appendix 11 : Total World Fleet

Year Start	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mar-20*
Crude Tankers[1]	1,660	1,687	1,774	1,834	1,843	1,823	1,844	1,934	2,015	2,011	2,116	2,133
Product Tankers[2]	7,267	7,445	7,609	7,844	8,109	8,305	8,484	8,684	8,827	8,931	9,075	9,077
Chem/Spec. Tankers[3]	3,410	3,528	3,632	3,681	3,727	3,789	3,865	3,974	4,067	4,180	4,264	4,277
Tankers	**12,337**	**12,660**	**13,015**	**13,359**	**13,679**	**13,917**	**14,193**	**14,592**	**14,909**	**15,122**	**15,455**	**15,487**
Bulkers	7,666	8,638	9,473	10,107	10,473	10,770	10,990	11,136	11,372	11,611	11,957	12,010
Combos	63	68	50	29	24	23	19	15	12	8	8	8
All Bulk	**20,066**	**21,366**	**22,538**	**23,495**	**24,176**	**24,710**	**25,202**	**25,743**	**26,293**	**26,741**	**27,420**	**27,505**
LPG	1,141	1,168	1,188	1,196	1,226	1,251	1,316	1,389	1,438	1,439	1,463	1,473
LNG	334	359	371	371	385	414	443	474	504	555	592	595
Containerships	4,826	4,989	5,106	5,114	5,114	5,145	5,256	5,188	5,198	5,304	5,370	5,374
MPP	3,237	3,305	3,334	3,347	3,321	3,272	3,256	3,226	3,171	3,163	3,165	3,163
General Cargo	15,335	15,408	15,300	15,193	15,158	15,092	15,108	15,107	15,040	15,011	15,081	15,080
Ro-Ro	992	944	905	873	842	813	818	822	833	830	837	838
PCC	665	687	730	756	763	774	786	781	782	784	776	777
Reefer	1,739	1,672	1,607	1,498	1,482	1,473	1,476	1,471	1,447	1,425	1,419	1,417
Passenger & Cruise	7,231	7,274	7,343	7,410	7,467	7,565	7,701	7,827	7,995	8,182	8,373	8,385
Offshore[4]	6,863	7,311	7,642	7,915	8,250	8,628	8,909	9,046	9,090	9,070	9,028	9,026
Dredgers	1,885	1,923	1,959	1,998	1,999	2,014	2,018	2,035	2,040	2,045	2,059	2,058
Tugs	14,062	14,767	15,597	16,583	17,412	18,148	18,635	18,990	19,277	19,581	19,957	19,977
Other non cargo	2,194	2,231	2,278	2,321	2,357	2,399	2,435	2,470	2,518	2,541	2,579	2,580
Total	**80,570**	**83,404**	**85,898**	**88,070**	**89,952**	**91,698**	**93,359**	**94,569**	**95,626**	**96,671**	**98,119**	**98,248**

*Data based on the Clarksons Research world fleet of merchant vessels >=100 GT. Please note that figures do not take into account retrospective changes for Non-Bulk Fleets pre-1996, as indicated by the horizontal line. *Data as at start month. 1 Crude tanker fleet includes all uncoated tankers 55,000 dwt and above. 2 Product tanker fleet includes all coated non-IMO graded tankers, all IMO 3 tankers, all IMO 2 tankers 25,000 dwt and above which meet criteria: average tank size >3,000 cbm, or, where average tank size unknown, no of tanks<16 (25-40k dwt), <18 (40-55k dwt), <30 (55-85k dwt), tankers of unknown IMO grade 25,000 dwt and above, uncoated non-IMO graded tankers below 55,000 dwt and excludes specialised tankers and all tankers with stainless steel tanks. 3 Chemical tanker fleet includes IMO I tankers plus IMO II tankers not meeting product tanker criteria, tankers of unknown IMO grade <25,000 dwt, includes all stainless steel tankers not designated as specialised tankers, excludes other* *specialised tankers. Specialised tankers includes tankers designed for the carriage of specialist liquids (excluding chemical tankers). 4 Offshore fleet includes 'ship-shaped' offshore units only.*